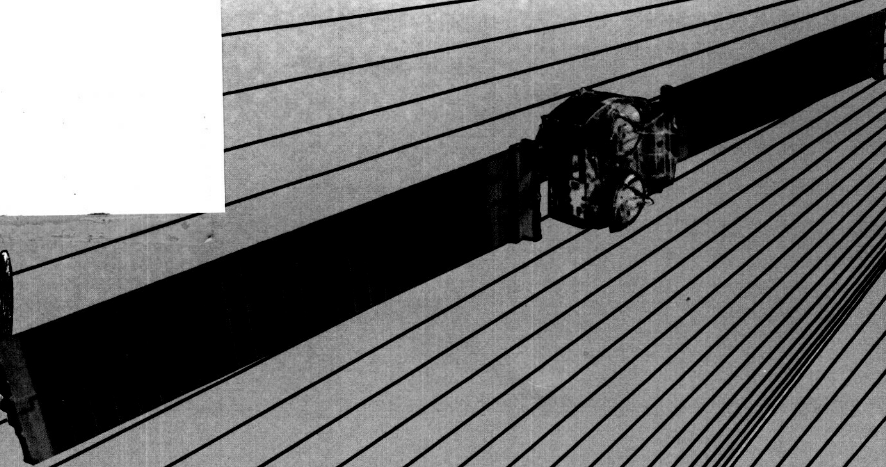

Annual Report 1988

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Annual Report 1988

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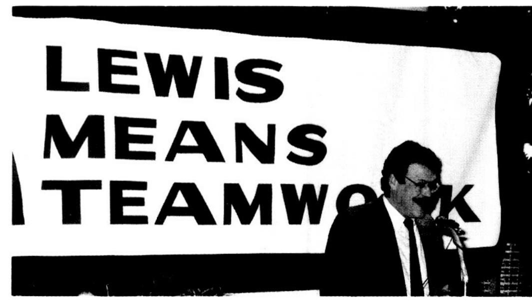
Introduction



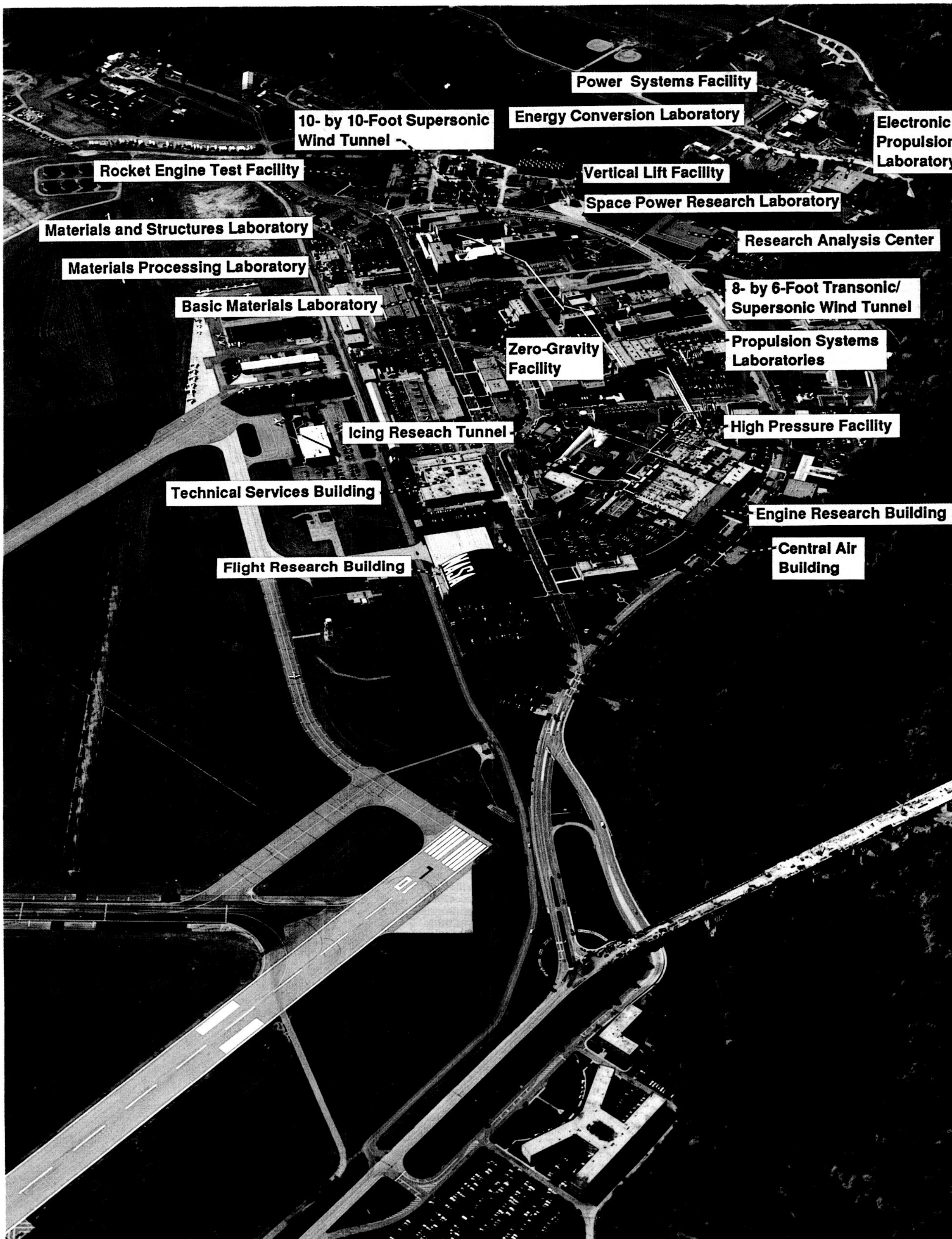
This booklet marks the first edition of an Annual Report of the Lewis Research Center. In June 1988 the senior staff endorsed the idea of expanding the content of the Research & Technology Annual Report of prior years into a more comprehensive annual report. As a result a greater effort has been made in soliciting and selecting articles that portray the achievements of the Center during fiscal 1988. The cover highlights two prestigious awards received by the Center—the Collier Trophy and the Emmy—for outstanding technical achievements in propulsion and communications. As a Center we are especially proud of these two achievements, but we take pride in the many other advances made during fiscal 1988. A sincere effort has been made to document them in this Annual Report. The report is organized topically to match the Center's Strategic Plan. It addresses the progress made in technological leadership and in providing the institutional support required to carry out our mission. In the interest of brevity and succinctness, detailed information important to a specialized topic or project often had to be omitted from this report. For such information Lewis published reports, technical journal articles, and other special publications should be consulted. Identified are principal investigators and project managers who can be contacted for further information.

This report is a testimony to the important cooperative relationships this Center has with industry, the university community, other NASA centers, and Government laboratories. These working relationships are vital to the execution of the major thrusts of the Center. Thus this report represents a cooperative enterprise among many within and outside the Center.

It is hoped that this report conveys the spirit of enthusiasm and dedication with which the Center addresses its important mission. These are exciting, challenging times in aerospace technology, and we are grateful for the opportunities to serve our Nation in the advancement of research and technology.

John M. Klineberg
Director

Inquiries regarding the report can be addressed to Dr. Robert W. Graham, Chief of the Technology Assessment Office, Mail Stop 3-17. The telephone number is (216) 433-5828 or FTS 297-5828.



Lewis Research Center:
Investment cost, $410 million
Estimated replacement cost, $2.3 billion

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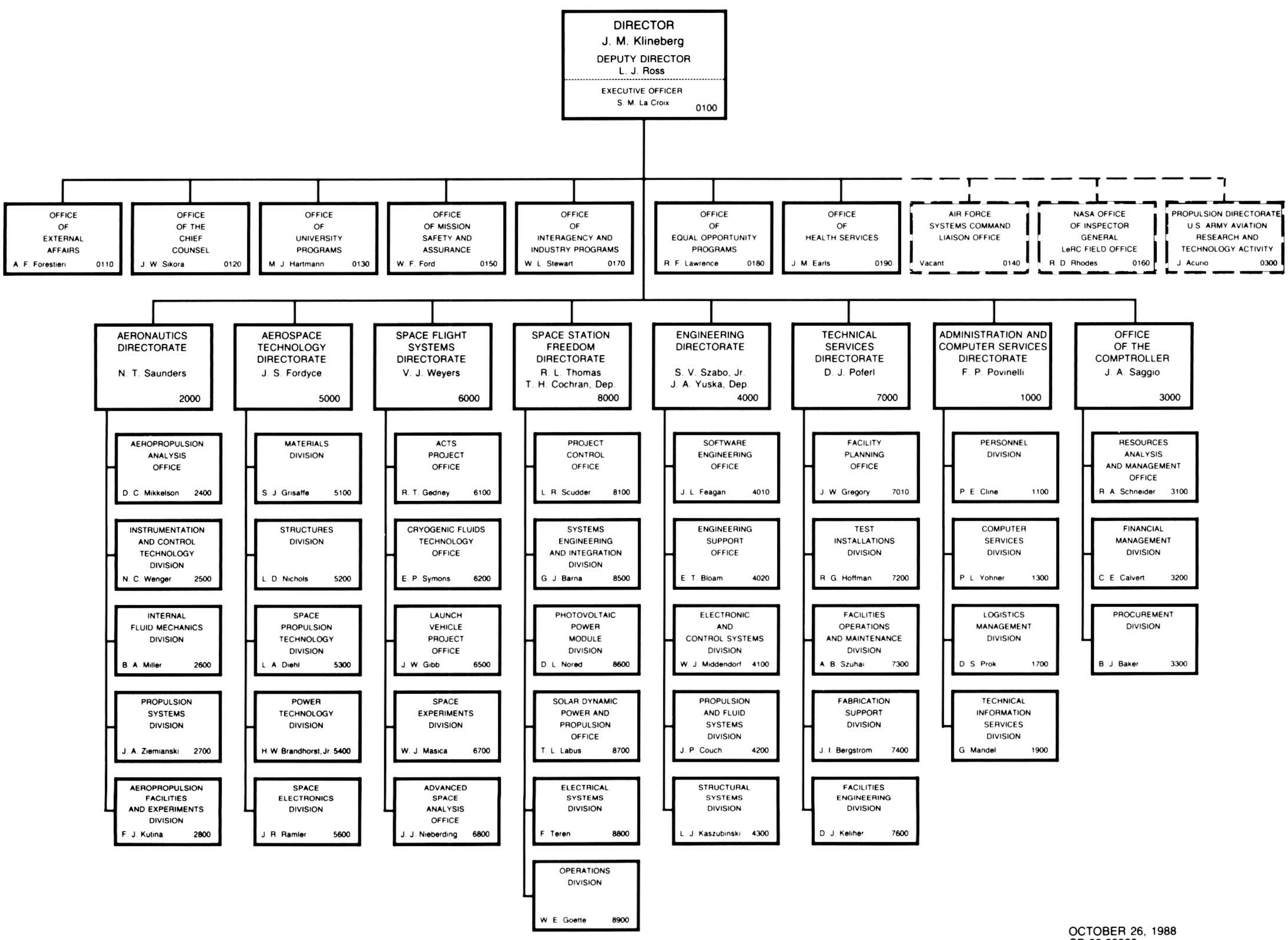
NASA Lewis Research Center



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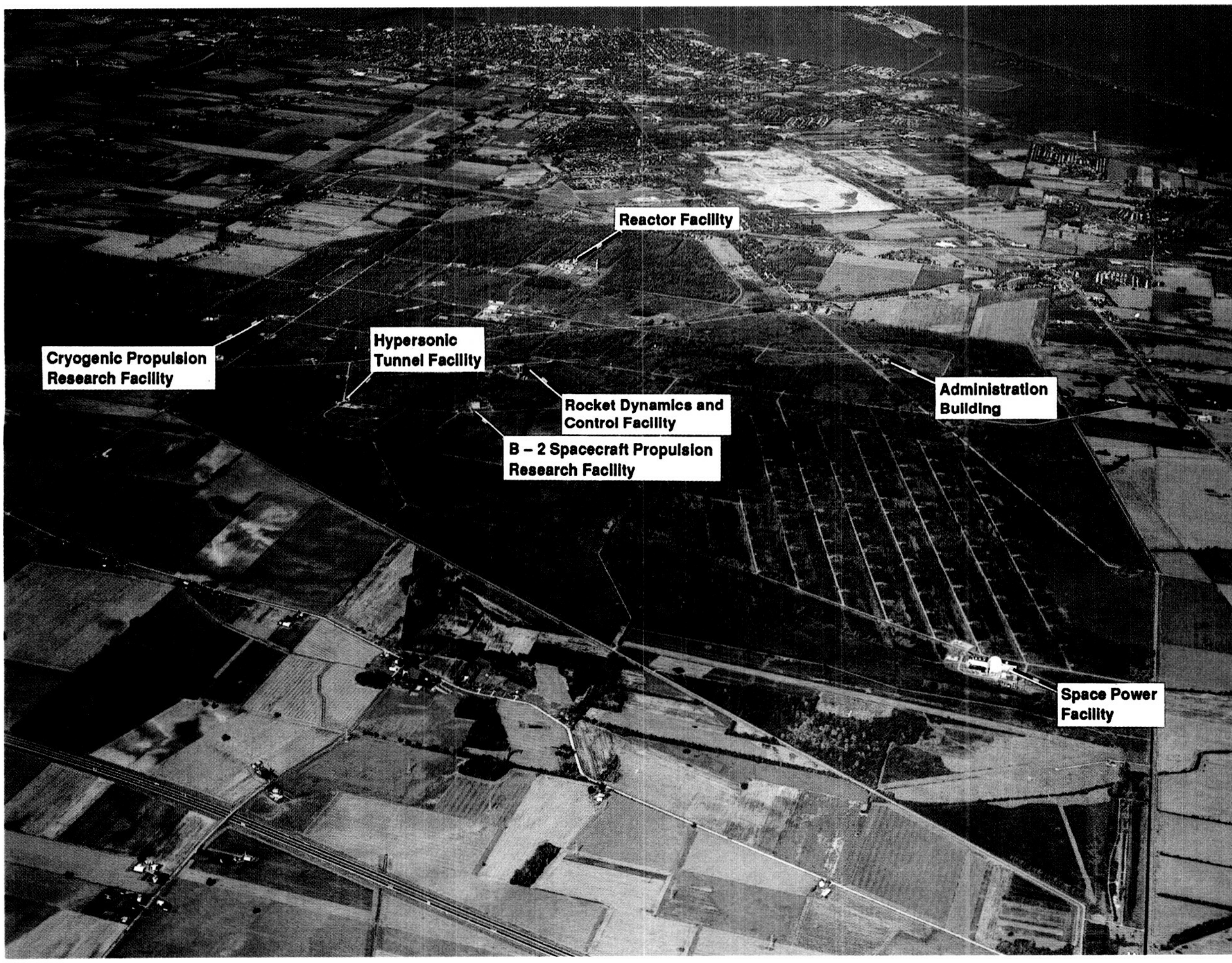

Plum Brook Station:

Original real property costs (excludes what other agencies and companies have invested), $98 million

Estimated replacement cost, $750 million

Contents

Basic Disciplines

Aeropropulsion

Space Propulsion

Space Power

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Computational, Information, and Communications Capabilities

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Basic Disciplines

Strategic Objectives

- To enhance Lewis' excellence in the basic and applied technical disciplines essential to our mission in aeropropulsion, space propulsion, space power, and space science/applications. These disciplines are materials science and technology, structural mechanics, life prediction, internal computational fluid mechanics, heat transfer, instruments and controls, and space electronics.

- To strengthen vertical integration of the various basic discipline areas with the major Lewis technology and project thrusts so that a continuum from fundamental to interdisciplinary applied work will be achieved.

- To gradually change the space electronics activities from primary emphasis on commercial communications needs to meeting future NASA needs, and to broaden this area to include basic and applied capabilities in fault-tolerant system autonomy and expert systems in support of space power and space propulsion thrusts.

Small Business Innovation Research

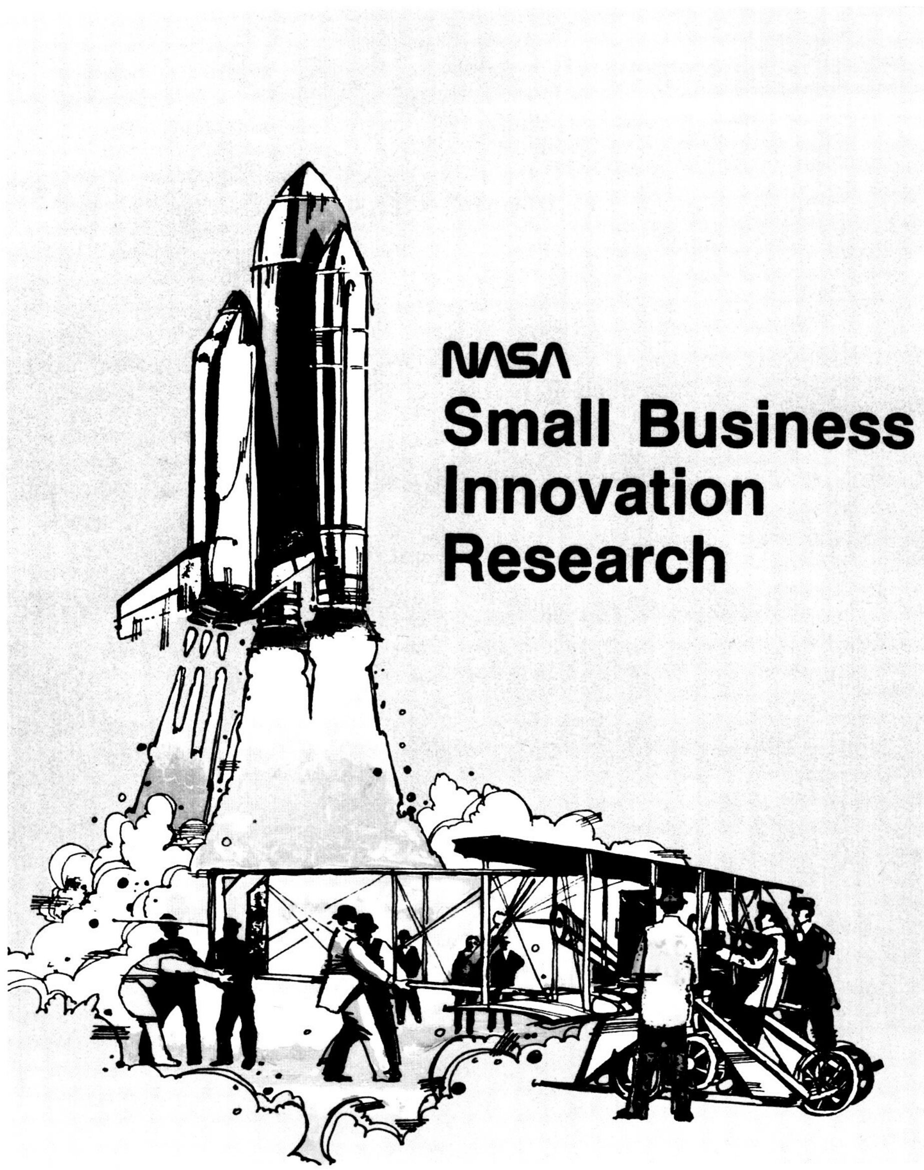
The Small Business Innovation Research (SBIR) Program is a congressionally mandated program aimed at the commercialization of innovative concepts by small business. These innovations are in general areas of research based on the needs of the U.S. Government. NASA is required to allocate 1.25 percent of its annual R&D budget appropriation to its SBIR program. Lewis' share of the SBIR budget was $6.5 million in 1987, and it is expected to stay the same for 1988.

SBIR funds only the first two phases of this three-phase program, but NASA program funds can be used in phase III for projects important to one of its programs. A phase I contract is for a maximum of $50,000 and is not to exceed 6 months. Successful phase I contracts are eligible to compete for a phase II award, which is not to exceed $500,000 and 24 months. Phase III is primarily for private sector investment to complete any development needed to commercialize the innovation.

During 1987, Lewis awarded 30 phase I SBIR contracts. Ten of these resulted in phase II awards. Two of these, which are important to aeronautics, will use Lewis facilities for testing. For the 1988 SBIR cycle 536 proposals were received. These will result in 30 to 35 phase I awards and about 10 to 13 phase II awards.

The Lewis Research Center participated in the NASA assessment of the SBIR program at the request of the General Accounting Office. In general the quality of research performed under the SBIR Program at Lewis was found to be above average. In one project on indium phosphide solar cells, outstanding research demonstrated a conversion efficiency of 18.8 percent, the highest ever obtained by this type of cell. Another recently completed project, which was part of the assessment, demonstrated high-quality research in synthesizing four new fluids as high-temperature lubricants. Lewis has found SBIR a productive way to involve small business in the nation's aerospace industry.

Lewis contact: Loretta M. Shaw, (216) 433-5658
Headquarters program office: OCP



Research & Technology

Materials

Strong, Tough Ceramic Composite Laminates

A high-temperature, fiber-reinforced ceramic composite has been developed at NASA Lewis that displays excellent strength and toughness plus noncatastrophic failure at strains significantly greater than tolerated by unreinforced monolithic ceramics. The composite consists of a reaction-bonded silicon nitride (RBSN) matrix reinforced by continuous high-performance silicon carbide (SiC) fibers. The excellent mechanical behavior of this SiC/RBSN composite is evident in tensile stress-strain curves. For example, for unidirectionally reinforced composites loaded along the fiber direction ($[0]_8$ layup), the matrix fractures at high composite stress (230 MPa), first point of nonlinearity. The material manifests toughness and noncatastrophic failure by its ability to remain integral at strain levels well above that for matrix fracture. The structural importance of these properties can be appreciated by comparing the curve for the $[0]_8$ composite with that for a monolithic, or unreinforced, RBSN.

Since many applications will require a structural material that can sustain biaxial loading, recent studies have examined the composite laminate approach in order to overcome the low strength of the unidirectional SiC/RBSN composites when tensile loaded transverse to the fibers (cf. the curve for a $[90]_8$ composite). By cross plying, in which the fiber direction in each composite lamina, or ply, is placed at 90° to the fiber direction in adjacent plies, symmetric SiC/RBSN laminates were fabricated and tensile tested.

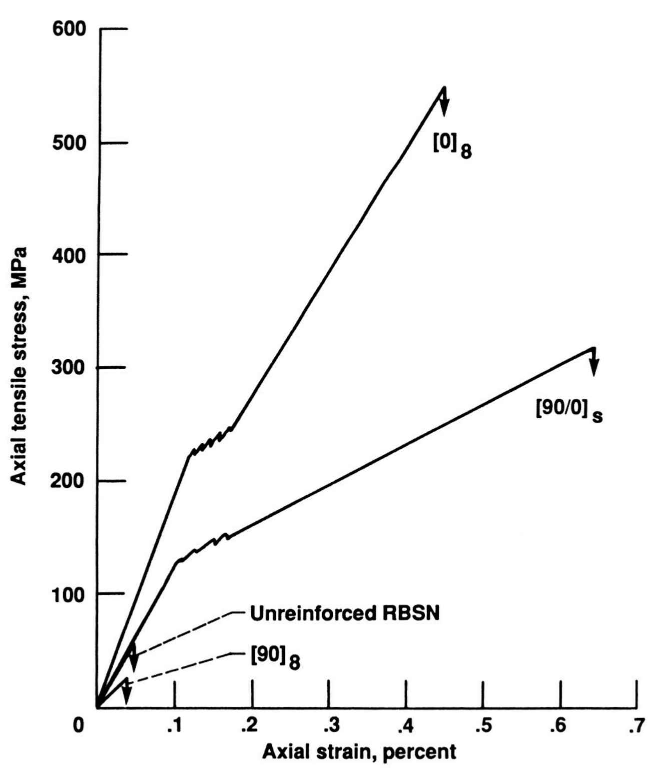
The curve for a $[90/0]_s$ shows that this composite behaved very similarly to the undirectional $[0]_8$ composite when tensile tested either along or perpendicular to the [0] plies. Although, as predicted, stiffness and strength were diminished because of a 50 percent loss of stiff fibers in the stress direction, matrix fracture strain was unaffected and composite ultimate strain was improved. This was not predicted but occurred even though 50 percent of the plies were stressed transverse to the fibers. The strain-strain responses of symmetric $[+45/-45]_s$ laminates were also similar to those of $[90/0]_s$ laminates.

Thus for the NASA ceramic composite the laminate approach has significant performance benefit in that it eliminates the transverse weakness of unidirectional composites while allowing the excellent axial toughness and strain capability of the unidirectional composites to be manifested in two directions.

Bibliography

Bhatt, R.T.: Properties of SiC-Reinforced Si_3N_4 Composites. Presented at the International Conference on Whisker- and Fiber-Toughened Ceramics, American Society for Metals, Metals Park, OH, 1988. To be published.

Lewis contact: Dr. Ramakrishna T. Bhatt, (216) 433-5513
Headquarters program office: OAST



Room-temperature axial stress-strain behavior for SiC/RBSN composite laminates

Inspection of Flaws in Ceramic Specimens by Scanning Laser Acoustic Microscopy

Scanning laser acoustic microscopy (SLAM) is an attractive technique for nondestructively inspecting ceramics because it can image surface and subsurface microflaws in real time. The detection of such flaws is important because they limit the strengths and fracture toughnesses of ceramic parts in advanced high-temperature heat engines.

In SLAM a laser light is used to detect distortions, on an angstrom scale, produced on the surface of a specimen by ultrasonic waves transmitted through the specimen. From the distortion SLAM creates a picture on a video monitor of such defects as voids, inclusions, and cracks.

Specimens of sintered Si_3N_4 and SiC, both as fired and polished, were examined by SLAM at an ultrasonic frequency of 100 MHz. The specimens were intentionally impressed with styrene microspheres during firing to introduce voids of known size, shape, number, and location in the surface.

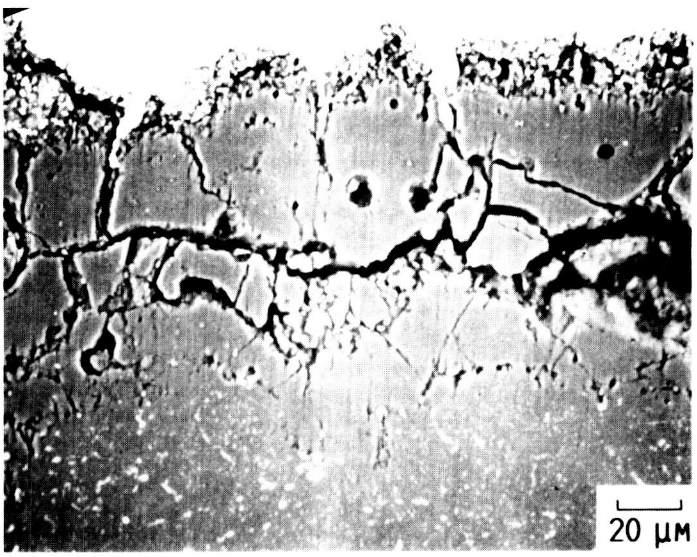
The evaluation concentrated on the statistical reliability of void detection by SLAM. SLAM detected surface voids as small as 100 μm in diameter in the polished specimens with 0.90 probability at a confidence level of 0.95. The reliability of detection was substantially less for voids in unpolished, as-fired specimens. Moreover, inspection of the as-fired specimens took 10 times as long as inspection of the smooth specimens. If ceramic engine parts are smoothly finished, as they are likely to be, the SLAM technique should detect surface and near-surface flaws quickly and reliably.

Lewis contacts: Don J. Roth, (216) 433–6017; Stanley J. Klima, (216) 433–6020; James D. Kiser, (216) 433–3247
Headquarters program office: OAST

Corrosion of Cordierite

Cordierite—magnesium alumina silicate—is a prime candidate for the regenerator material in the advanced gas turbine engine. This material has exceptional high-temperature stability and a low thermal expansion coefficient. In discussions with Garrett Turbine Engine Company, however, it became apparent that the regenerator in this engine may be a site for sodium-sulfate (Na_2SO_4)-induced corrosion. Therefore cordierite was examined in both laboratory and burner rig corrosion tests.

Coupons of cordierite were made



Polished cross section of cordierite corroded in a burner for 40 hr at 1000 °C with 2 ppm Na as NaCl

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by cold pressing and sintering. The coupons were coated with Na_2SO_4 and treated in a laboratory furnace. The reaction products were analyzed, and it appears the following reaction occurred to a limited extent:

$$2Na_2SO_4(\ell) + Mg_2Al_4Si_5O_{18}(s) = 4NaAlSiO_4(s) + Mg_2SiO_4(s) + SO_2(g) + O_2(g)$$

In addition to this chemical attack, corrosion appeared to induce cracking in the cordierite substrate. The cracking was the more severe result of the corrosion. Burner rig tests with no. 2 diesel fuel at 1000 °C and 2 ppm Na injected as NaCl produced results similar to those obtained in the laboratory tests. Both the chemical attack and the cracking must be considered in combustion applications of cordierite.

Bibliography

Jacobson, N.S.; and Bianco, R.: Corrosion of Cordierite Ceramics by Sodium Sulfate at 1000 °C. Submitted to J. Mater. Sci., 1988.

Lewis contact: Nathan S. Jabobson, (216) 433-5498
Funding source: DOE

Corrosion Regimes for Silica-Protected Ceramics

A key corrodent in combustion applications is molten sodium sulfate (Na_2SO_4) formed by the reaction of sulfur impurities in the fuel with ingested sodium. Extensive studies at NASA Lewis have shown that silica-protected ceramics such as silicon carbide (SiC) and silicon nitride (Si_3N_4) are quite susceptible to attack by sodium sulfate. Corrosion occurs in two steps: the molten sodium sulfate is deposited, and the protective silica scale is dissolved. The conditions under which these processes occur were calculated, and corrosion regimes were defined.

The final results are presented as diagrams of the SO_3 pressure [$P(SO_3)$] in the engine versus temperature. Corrosion regimes fall within boundaries set by these variables. The lower temperature boundary for corrosion is the melting point of Na_2SO_4, and the upper boundary is the dewpoint for Na_2SO_4 deposition. This dewpoint is a function of pressure and concentration and was calculated from the NASA chemical equilibrium code. Consider next the $P(SO_3)$ in the engine. The critical $P(SO_3)$ for corrosion was calculated from this reaction:

$$Na_2SO_4 + 2SiO_2 = Na_2O \cdot 2(SiO_2) + SO_3$$

The levels of SO_3 generated by the combustion process were also calculated from the NASA chemical equilibrium code. When these levels were below the critical $P(SO_3)$ and within the temperature limits, corrosion was predicted.

Calculations were made for a variety of operating pressures and impurity contents. Where possible, the predictions were verified experimentally in burner rig corrosion tests. Possible deviations from these idealized calculations were also explored. Using these calculations should enable the engine designer to understand when hot corrosion of silica is a potential problem.

Bibliography

Jacobson, N.S.; and Smialek, J.L.: Hot Corrosion of Sintered-SiC at 1000 °C. J. Am Ceram. Soc., vol. 68, no. 8, Aug. 1985, pp. 432–439.

Jacobson, N.S.; and Fox, D.S.: Molten-Salt Corrosion of Silicon Nitride: II, Sodium Sulfate. J. Am. Ceram. Soc., vol. 71, no. 2, Feb. 1988, pp. 139–148.

Jacobson, N.S.: Sodium Sulfate: Deposition and Dissolution of Silica. Submitted to Oxid. Metals.

Lewis contact: Nathan S. Jacobson, (216) 433-5498
Headquarters program office: OAST

Fundamental Properties of Solids and Interfaces

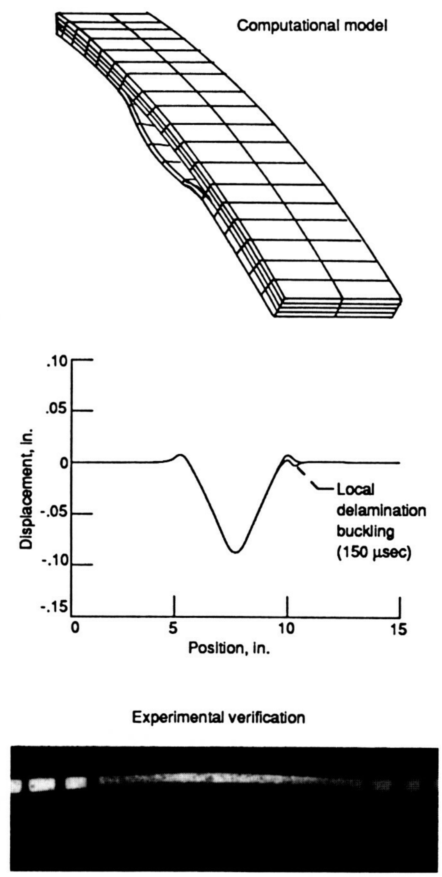
Current theoretical research into the fundamental properties of solids and interfaces involves the extension of universality in binding energy relations, the equation of state for solids, and the energetic and electronic properties of defects in solids (e.g., grain boundaries). Progress has been made in discovering a universal equation of state for Van der Waals, ionic, covalent, and metallically bonded solids. These results have been applied to predicting the isothermal temperature dependence of the bulk modulus and its derivatives and the thermal expansion for all classes of solids. Also, the relationships between all the most widely used heuristic equations of state have been established. Some preliminary work is being performed in examining phase changes. The grain boundary studies involve implementing and improving on some new techniques—the equivalent crystal theory and the embedded atom method—for calculating energies, including the many-body interactions. The equivalent crystal theory is presently being used to study adhesion, shear, and the atomic force microscope. The embedded atom method is being used to improve the Frenkel model for shear. Universality is being generalized to cases with charge transfer for diatomics, with the hope that it can be applied to solids, extending the techniques to ceramics and metal-ceramic interfaces. Fully quantum mechanical calculations by the linear muffin-tin orbital method are being used to examine the band structure of photovoltaic materials and the equations of state for ionic solids.

Lewis contact: Dr. John Ferrante, (216) 433-6069
Headquarters program office: OAST

Structural Mechanics

Impact-Induced Delamination Buckling in Composite Laminates

NASA Lewis has developed a unique dynamic buckling and delamination propagation analysis and incorporated it into the MSC/NASTRAN finite-element computer program. This capability consists of (1) a modification of the direct time integration solution sequence, which provides a new analysis algorithm that can be used to predict delamination buckling in a laminate subjected to dynamic loading and (2) a new method of modeling the composite laminate with plate bending elements and multipoint constraints. The modified version of NASTRAN can now be used to predict both impact-induced buckling in composite laminates with initial delaminations and the strain energy release rate due to extension of the delamination. Results obtained with the new computational algorithm show that delaminations near the outer surface of a laminate are susceptible to local buckling and buckling-induced delamination propagation when the laminate is subjected to transverse impact loading. We can now predict the time at which the onset of dynamic delamination buckling occurs, the dynamic buckling mode shape, and the dynamic delamination strain energy release rate.



Experimental verification of finite-element representation of buckling

Comparisons between the experimental results of high-speed photography and analysis show that the new dynamic buckling analysis can be used to computationally predict the dynamic resistance of graphite/epoxy specimens. A decrease in stiffness, such as that caused by impact damage, results in a corresponding decrease in the natural frequencies of the damaged composite structure. To determine the extent of this effect, we measured the first four natural frequencies of a series of cantilevered graphite/epoxy composite specimens with initial embedded delaminations before and after impact. The measured reduction in the natural frequencies of the first four bending modes for varying amounts of impact damage compared well with the results of a two-dimensional finite-element simulation of the damaged specimens. The results indicated that the finite-element representation accurately models the low vibration modes of both damaged and undamaged specimens of the geometry. In addition, the higher frequencies were progressively more sensitive to delamination damage.

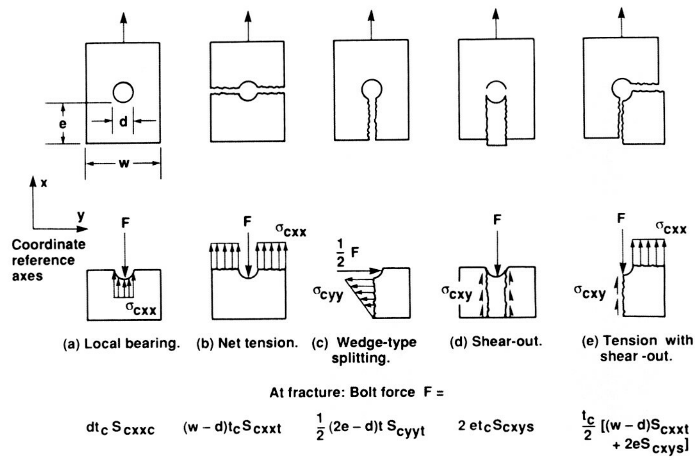
Lewis contact: Joseph E. Grady, (216) 433-6728 or (216) 433-3186
Headquarters program office: OAST

Life Prediction

Simplified Procedures for Designing Composite Bolted Joints

The structural integrity of composite structures is often determined by the integrity and durability of their respective joints. The two general classes of joints are mechanical fasteners and adhesive bonding. The integrity of mechanical fastener joints depends mainly on the local laminate bearing strength; the integrity of adhesively bonded joints depends mainly on the local interlaminar shear strength.

Research at NASA Lewis led to the development of simplified methods for predicting microstresses and local laminate strengths, including interlaminar strengths. These methods are applicable to the design of bolted joints for composite structures since bolted joints must resist certain select failure modes. These select failure modes, those most commonly occurring in practical applications, include local bearing, tension, wedge splitting, shear-out, and tension with shear-out. By applying the simplified methods for predicting local laminate strength in conjunction with bolted joint failure modes, we derived a set of approximate equations.



Failure modes and respective equations for composite bolted joints

Bibliography

Chamis, C.C.: Simplified Procedures for Designing Composite Bolted Joints. NASA TM–100281, 1988.

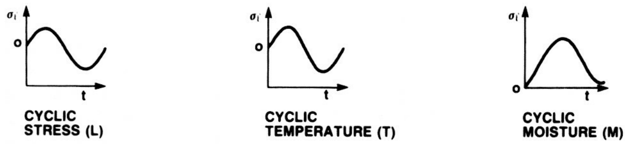
Lewis contact: Dr. Christos C. Chamis, (216) 433–3252
Headquarters program office: OAST

Computational Simulation of Hygrothermo-mechanical Fatigue for Fiber Composites

The technology of advanced fiber composites has matured to the point where these composites are prime contenders for various structural applications. A major design consideration for their prolonged service is fatigue due to cyclic hygral (moisture), thermal, and mechanical (hygrothermomechanical) loading conditions. Recent research has led to the development of formal procedures for using computational simulation to predict fatigue in fiber composites that is due to cyclic hygrothermo-mechanical loading conditions. These formal procedures have subsequently been programmed into a computer module and embedded into the Integrated Composites Analyzer (ICAN) computer code.

When exposed to thermal cycles composites often experience the phenomenon known as micro-cracking or transply cracking. Designers are therefore interested in the number of cycles that cause the initial crack. Since many of these components are critical (life limiting) items relative to the entire structure, reliable life prediction is an important issue. For this purpose relationships have been derived that use the variables of temperature ranges, degradation coefficient, ply strength and stress, and cyclic temperature amplitudes to predict the number of cycles to the initial crack. These relationships can be applied to a single type of fatigue load as well as to combined loading, which is often the state of composite structures in an aerospace propulsion system.

Durability, life, or both are assessed in terms of the remaining strength ratio after degradation (margin of safety) with respect to a prescribed number of cycles. This simplified equation accounts for the combination of environmental and mechanical loads on a ply-by-ply basis. Although these theories have not



$$\left(\frac{S_{\ell cyc}}{S_{\ell o}}\right) = F_{HT} - B_L \,\text{Log}\, N_L \qquad \left(\frac{S_{\ell cyc}}{S_{\ell o}}\right) = F_{HT} - B_T \,\text{Log}\, N_T \qquad \left(\frac{S_{\ell cyc}}{S_{\ell o}}\right) = F_{HT} - B_M \,\text{Log}\, N_M$$

$$\text{WHERE } F_{HT} = \left[\frac{T_{GW} - T}{T_{GD} - T_o}\right]^{1/2}$$

$$\left(\frac{\sigma_{\ell cyc}}{S_{\ell cyc}}\right)_L + \left(\frac{\sigma_{\ell cyc}}{S_{\ell cyc}}\right)_T + \left(\frac{\sigma_{\ell cyc}}{S_{\ell cyc}}\right)_M < 1/K_T \qquad \text{WHERE } K_T = \text{STRESS CONCENTRATION FACTOR}$$

Combined hygrothermomechanical cyclic loading equation

been verified experimentally because of a lack of relevant data, they are quite suitable for preliminary design purposes.

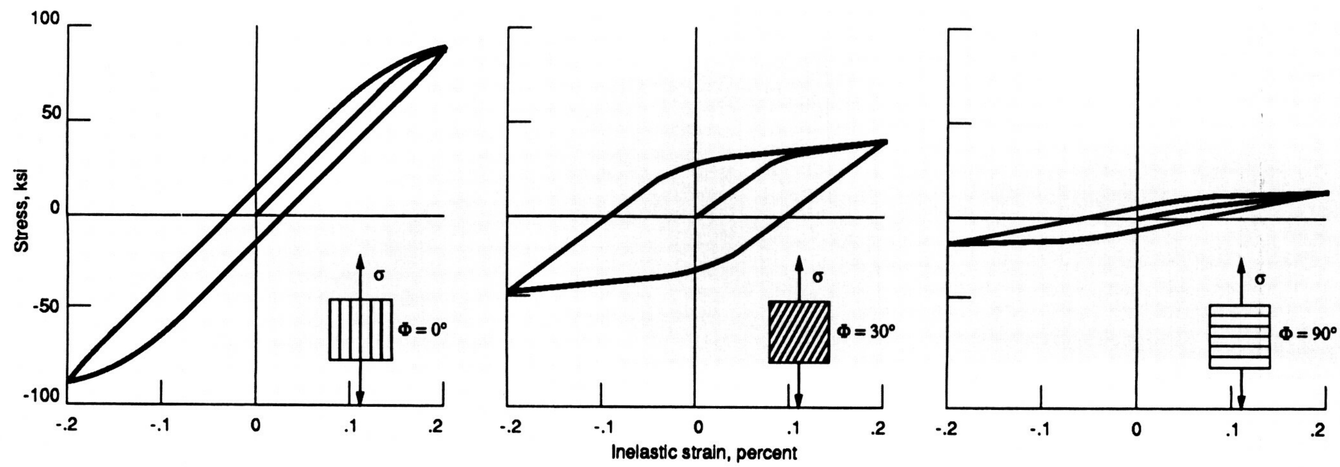
Bibliography

Ginty, C.A.; and Chamis, C.C.: Hygrothermomechanical Fiber Composite Fatigue: Computational Simulation. NASA TM–100840, 1988.

Lewis contact: Carol A. Ginty, (216) 433–3335
Headquarters program office: OAST

Continuum Deformation Theory for Metallic Composites at High Temperatures

The design engineer requires reasonably simple structural analysis methods for predicting deformation behavior at high temperatures, where material response is complex. Experiments have suggested that a composite material has its own unique properties that can be measured and specified. On the basis of this characteristic a continuum theory has been formulated for representing the high-temperature deformation behavior of metallic composites that can be idealized as pseudohomogeneous continua with local definable directional characteristics. The result is a relatively simple multiaxial constitutive theory that is easily implemented into existing structural analysis computer codes for predicting high-temperature deformation response to complex loading histories.



Hysteresis loops at fiber orientation angles Φ of 0°, 30°, and 90°, change in inelastic strain of 0.4 percent, and inelastic strain rate of 0.001/m

Predicted hysteresis loops under constant-strain-range and constant-strain-rate uniaxial loading for various fiber orientations relative to the loading direction show strain-rate-dependent plasticity and the expected directionality.

Bibliography

Arya, A.K.; and Robinson, D.N.: Finite Element Analysis of Metal-Matrix Composite Structures. Presented at ASME/SES Summer Annual Meeting, Berkeley, CA, 1988. To be published in J. Eng. Mater. Technol.

Robinson, D.N.; and Duffy, S.F.: A Continuum Deformation Theory for Metallic Composites at High Temperature. To be published in J. Eng. Mech. ASCE, 1988.

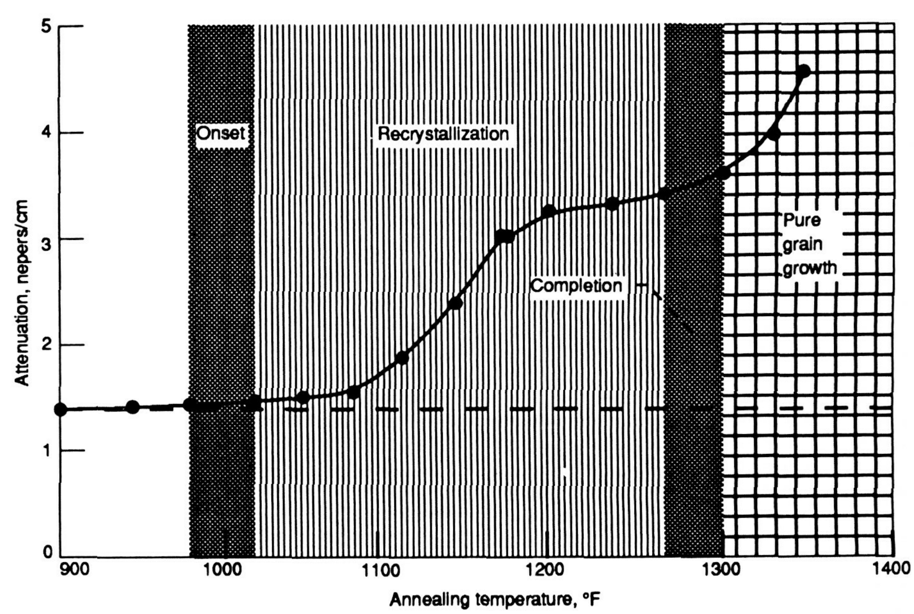
Robinson, D.N.; Duffy, S.F.; and Ellis, J.R.: A Viscoplastic Constitutive Theory for Metal-Matrix Composites at High Temperature. Thermal Stress, Material Deformation, and Thermo-Mechanical Fatigue, H. Sehitoglu and S.Y. Zamrik, eds., ASME, 1987, pp. 49–56.

Lewis contact: David N. Robinson, (216) 433-3339
Headquarters program office: OAST

Ultrasonic Determination of Recrystallization

Cold working is a common method of strengthening metals. With increased cold work, strength increases—up to a limit. The microstructure of the metal becomes increasingly distorted with increased work and exhibits high internal stresses. These residual stresses are detrimental to the final structure. The reduction of stresses in the material is obtained by interrupting the cold-working process to anneal the material by heating. A repetitive process of mechanical work followed by subsequent annealing at the recrystallization temperature yields a material with optimum properties (small grains) and low residual stresses.

One complication in this thermomechanical treatment is that the recrystallization temperature varies with the amount of work in the material. The recrystallization temperature must therefore be determined at each step of the treatment for optimum results. X-ray metallography and analysis by transmission electron microscopy individually cannot completely characterize the state of the recrystallization process. However, the ultrasonic attenuation, being extremely sensitive to the formation of small scatterers and having a wide dynamic range to large scatterers, is a viable, nondestructive, and convenient method for characterizing the



Correlating ultrasonic attenuation and temperature determines effect of annealing on work-hardened materials

recrystallization process. Ultrasonic attenuation was measured in cold-worked nickel 200 (99.5+ percent Ni) annealed at ever higher temperatures. Localized variations in the density of dislocations, the crystalline order, and the volume percent of recrystallized phase were determined over the range of annealing temperatures by transmission electron microscopy, x-ray diffraction, and metallography. The exponent of the frequency dependence of the attenuation has been found to be a key variable that can be used to relate the ultrasonic attenuation to the thermal kinetics of the recrystallization process.

Bibliography

Generazio, E.R.: Ultrasonic Determination of Recrystallization. NASA TM-88855, 1987.

Lewis contact: Dr. Edward R. Generazio, (216) 433-6018
Headquarters program office: OAST

Fortran Algorithm for Image Processing

A Fortran computer algorithm that contains various image-processing analysis and enhancement functions has been developed at NASA Lewis. The algorithm was developed specifically to process images of developmental heat-engine materials obtained with sophisticated nondestructive evaluation instruments.

Digital image processing has found many applications in scientific, biomedical, and industrial areas. Specific applications include the automatic classification of terrain through pattern-recognition techniques, the formation and enhancement of biomedical imagery, and the enhancement of radiographs and acoustic images of critical components containing possible flaws.

A variety of image-processing systems are available, and the level of software developed for each system varies. The image processor is sometimes provided by the manufacturer as part of a minicomputer system. Such a system may include user-friendly software that requires little, if any, additional programming by the purchaser. The image processor may also be purchased separately from a computer system and then must be integrated into the system. Software may be provided and would have to be organized by an experienced computer programmer in order to develop powerful image-processing capability.

The subject Fortran program was developed for a Grinnell 274 image processor interfaced with a Digital PDP 11/45 minicomputer. Its task file requires 64 kilobytes (125 blocks) of memory. The program was written by using software routines provided by Grinnell. Considerable additional Fortran programming was required for organizing the routines to perform the desired functions. The program's nine subroutines are displayed on a main menu. The subroutines are chosen by using a computer keyboard. Within the subroutines are other routines, also selected via keyboard.

The functions performed with this program include digitization, storage, and retrieval of images; image enhancement by contrast expansion, addition and subtraction, magnification, inversion, and

bit shifting; display and movement of a cursor; display of a plot of the number of image pixels versus the gray level (gray-level histogram of the image); and display of a plot of the variation of the gray levels as a function of position within the image. Possible applications of this program include scientific, industrial, and biomedical imaging for studies of flaws in materials, analyses of steel and ores, and pathology, respectively.

Lewis contacts: Don J. Roth, (216) 433-6017; David R. Hull, (216) 433-3281
Headquarters program office: OAST

Computer Program for Assessing Ability of Inspection Techniques to Find Structural Flaws

A versatile Fortran computer algorithm has been developed at NASA Lewis for calculating and plotting the reliability of a nondestructive evaluation (NDE) technique for inspecting flaws. The algorithm was developed specifically to determine the reliability of radiographic and ultrasonic methods for detecting critical flaws in structural ceramic materials. Reliability is displayed as a plot of the probability of detection (at a selected confidence level) versus the flaw size.

NDE methods are used in such applications as diagnostic medicine, quality control in industrial production, and the prediction of failure in structural components. In the latter application, sensitive, reliable NDE techniques are needed to detect flaws and reject those parts containing critical flaws or concentrated flaw populations and to aid in the optimization of processes by identifying the fabrication stages during which flaws are introduced.

The reliability of an NDE inspection technique is a quantitative measure of the ability of that technique to detect flaws of a specific type and size in a particular material. In experiments to determine reliability, specially prepared specimens containing a known number of accurately characterized flaws are inspected. Data are gathered on the number and size of the flaws detected. By applying binomial-distribution statistical theory to these data, reliability is then calculated in terms of the probabilities of detection at specific confidence levels for various flaw sizes. This calculation requires great computational effort.

An application of the technique includes the determination of the reliability of an NDE inspection technique for detecting such critical flaws as voids, cracks, foreign impurity particles, and delaminations in metal, ceramic, polymeric, and composite structural components. Industrial interests might include developers of NDE inspection equipment who wish to evaluate the reliability of the equipment for flaw detection and producers and users of structural components who use NDE methods to detect flaws deemed critical to component integrity.

Lewis contact: Don J. Roth, (216) 433-6017
Headquarters program office: OAST

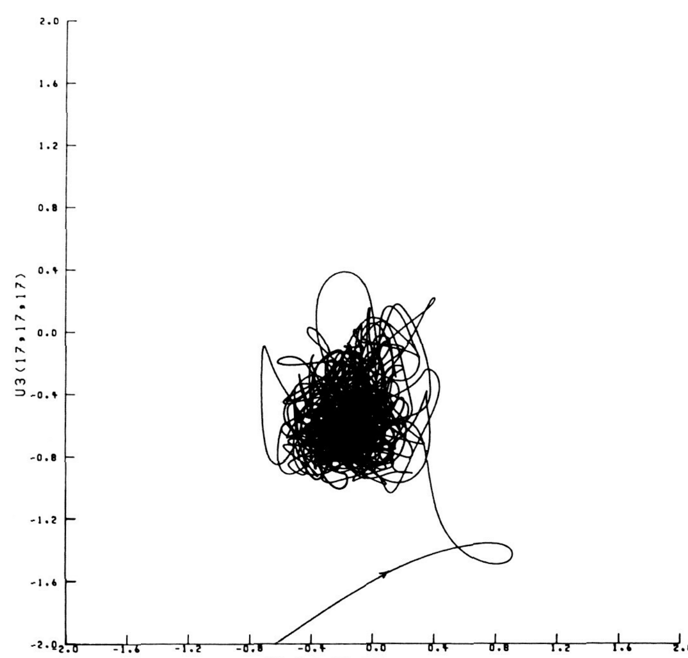
Internal Computational Fluid Mechanics

Simulation of Multistage Turbomachinery Flows

A flow model has been formulated for use in simulating multistage turbomachinery flows that is compatible with today's supercomputers and those currently under development. This model describes the three-dimensional, time-averaged flow field in a typical blade passage of a multiblade-row machine. This flow model is referred to as "the average-passage flow model." A computer code based on earlier work has been written to solve the viscous form of the average-passage equation system.

A stage-and-a-half turbine configuration is being analyzed with the viscous code. To date, the simulation has yielded new insight into the unsteady flow processes that control the performance and time-averaged thermal loads in multistage turbines. It appears that the unsteady flow associated with the horseshoe vorticities plays a key role in transporting momentum and energy across time-averaged stream surfaces. The ability to account for this unsteady process in the design of multistage turbines should yield significant improvements in efficiency and life.

Lewis contact: Dr. John J. Adamczyk, (216) 433–5829
Headquarters program office: OAST



Characterization of turbulence

Characterization of Turbulence

Most fluid flows, including those occurring in nature and those that are man-made, are turbulent. To characterize fluid turbulence, NASA Lewis has numerically obtained turbulent solutions of the equations of fluid motion. We have determined that the nonlinear terms in the equations have a randomizing effect and that the solutions are chaotic in the sense that the instantaneous values are extremely sensitive to small changes in initial conditions. With steady forcing the flow at moderate Reynolds numbers is attracted at large times to a region of phase space known as a strange (or chaotic) attractor. That is the black region in the representation of phase space shown in the figure, where a velocity component at one point is plotted against a component at another point. The arrow shows the direction of increasing time. Once the flow is attracted to the black region (black hole), it tends to remain there.

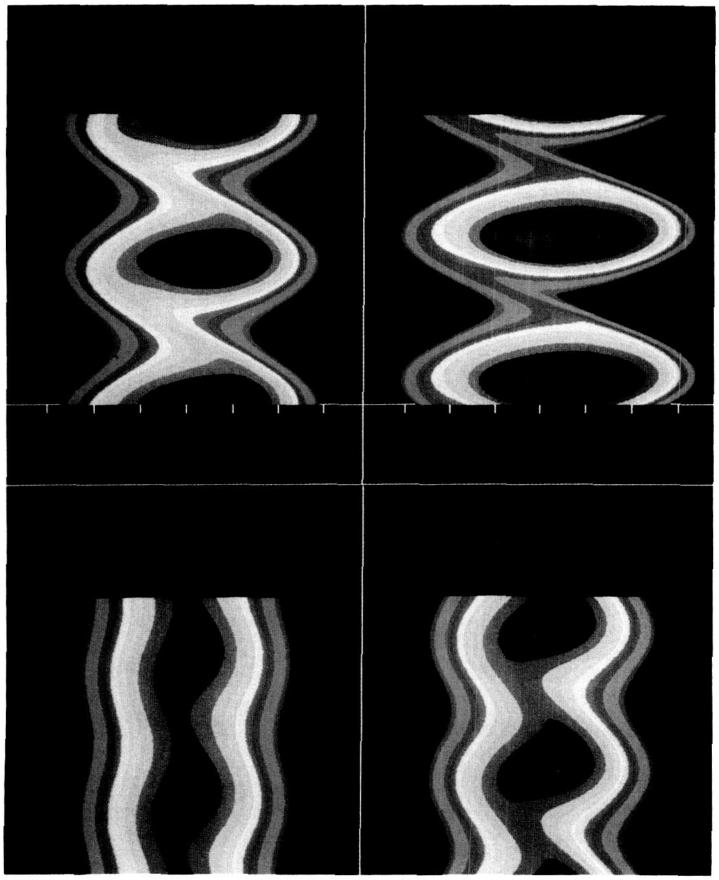
Lewis contact: Robert G. Deissler, (216) 433–5823
Headquarters program office: OAST

Enhancement of Turbulent Mixing

Considerable technological interest has arisen in using small-amplitude external excitation for controlling mixing in free shear layers. The external excitation produces spatially growing instability waves that are initially governed by linear dynamics if the excitation amplitude is sufficiently small. A disturbance that evolves from the strictly linear finite-growth-rate instability wave on weakly nonparallel mean flow has been analyzed. The nonlinear effects first become important in the so-called critical layer. A composite expansion technique is used to obtain a single formula that accounts for both shear layer spreading and nonlinear critical layer effects. Nonlinearity causes the instability to saturate well upstream of the linear neutral stability point. It also produces vorticity rollup that is quite different from that predicted by linear theory.

The numerical results show that even a very small viscosity eventually asserts itself as smaller scales are generated by the nonlinear critical layer effects. The critical layer vorticity distribution diffuses into a more regular pattern vis-à-vis the inviscid case, and the instability wave growth ultimately becomes algebraic. The far-downstream critical layer vorticity balance is between linear and nonlinear convection terms, and an equilibrium critical layer is approached. The solution is used to infer the scaling for the next stage of flow evolution. The instability wave growth is simultaneously affected by mean flow divergence and nonlinear critical layer effects in this latter stage of development.

The most rapidly growing instability waves in supersonic shear layers are three-dimensional, and the analysis has been extended to include three-dimensional effects. These effects dramatically change the nonlinear behavior, which now becomes important at much smaller amplitudes than in the two-dimensional case. The effects of combustion are also being considered.



Velocity rollup and evolution toward a quasi-equilibrium critical layer for a harmonically forced, incompressible free shear layer

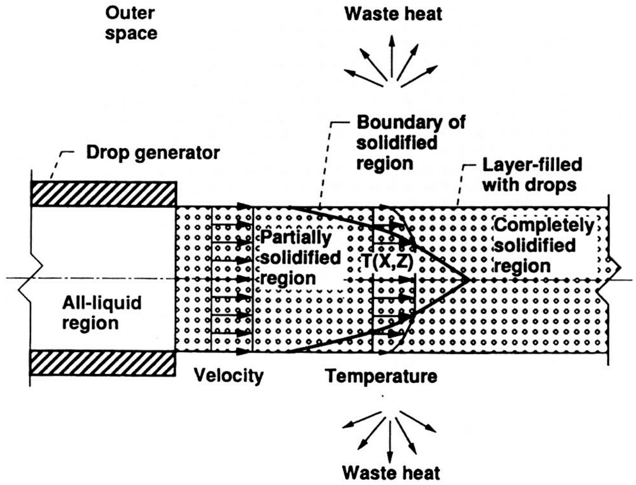
Lewis contacts: Dr. Marvin E. Goldstein, (216) 433–5825; Dr. Lennart S. Hultgren, (216) 433–6070
Headquarters program office, OAST

Heat Transfer

Transient Radiative Cooling of Emitting and Scattering Regions

Several analytical studies were performed to examine the radiative characteristics of a region filled with a medium that can emit, absorb, and scatter radiation. The transient energy equation, coupled with the equation of radiative transfer, was solved numerically to yield the radiative ability of the region. The transient cooling behavior indicated that, following an initial period, a similarity solution is achieved for which the emittance of the region becomes constant with time. The radiative behavior has application to the liquid-drop radiator, a potentially lightweight device for dissipating waste heat in space. The analysis has included freezing of a liquid radiating medium so that both latent and sensible heat can be utilized for the energy dissipation process. Current work is on the radiative behavior of rectangular regions. Multidimensional radiative transfer is in need of further research because of the difficulties in solving the governing integral equations.

Lewis contact: Dr. Robert Siegel, (216) 433-5831
Headquarters program office: OAST



Layer of liquid drops moving through space that cool and solidify to radiate away waste heat (horizontal dimension is shown compressed)

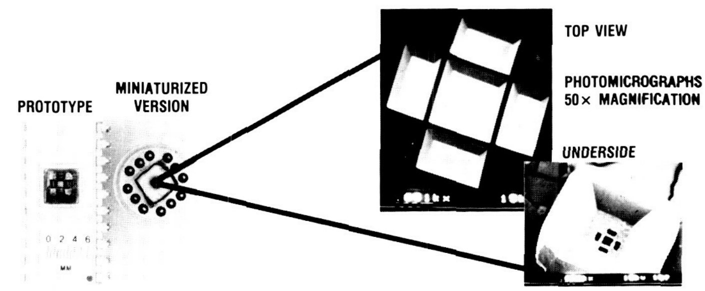
Instrumentation and Controls

Ultrasensitive Microelectronic Air and Gas Flow Transducer

During the past year researchers at the University of Cincinnati have succeeded in reducing the size of the UC–NASA microtronic mass flow transducer to fit on the head of the proverbial pin. The result is a demonstrated thousand-fold decrease in response time from seconds to milliseconds and a three orders of magnitude increase in mass flow sensitivity. The payoff is a new ultrasensitive microelectronic gas flow transducer that could save many lives by providing very accurate monitoring and control of life-critical gases to postoperative patients and premature infants in incubators.

In addition, the microtronic transducer's miniature size, high sensitivity, and fast response with directional selectivity open new applications for measuring vortices, inlets to pipes, and other complex flow fields. Specific velocity measurements with little or no disturbance can be made of anomalous transient flows in pipes and chambers and along aerodynamic surfaces. Fast, accurate flow data will enhance proposed solutions to transient flow problems for the Stirling engine, for hot spots in large radiators on earthmoving equipment, for carburetor gas-fuel mixtures, and for turbine blades and aircraft flight surfaces.

Ultrasensitive microelectronic air and gas flow transducer



The UC–NASA microtronic mass flow transducer is a miniature Wheatstone bridge semiconductor version of the hot-wire anemometer. Being solid state, however, yields further advantages of ruggedness, reliability, greater resistance to contamination and much lower production costs. Because of its planar construction, auxiliary control electronics may be integrated onto the same chip with the potential of reducing costs of the sensor element to the $10 range when produced in quantity.

Lewis contact: Gale R. Sundberg, (216) 433–6152
Headquarters program office: OAST

Rayleigh Scattering for Nonintrusive Gas Density and Temperature Measurements

Nonintrusive measurements of gas density and temperature are needed for a better understanding of fundamental flow physics in both aircraft and spacecraft propulsion systems and as a data base for use in validating new predictive codes. Of the techniques available for these nonintrusive measurements, Rayleigh scattering (i.e., elastic light scattering from molecules) offers several attractive

features. The scattering cross section is much larger than that of other techniques such as spontaneous Raman, no seeding is required, and the equipment needed is relatively simple. Disadvantages, however, include the need for a flow that is free of particulates and the need for great care to prevent stray light from reaching the photodetector.

Two methods of applying Rayleigh scattering are being investigated at NASA Lewis. One is to simply illuminate a volume of the gas with laser light and then measure the intensity of the scattered light. Since the intensity of Rayleigh-scattered light is proportional to the number of molecules in the volume, this gives a direct measure of the gas density. One implementation of this technique was developed under a Small Business Innovation Research (SBIR) contract by Aerodyne Products, Inc. This system uses a copper-vapor laser coupled through a 10-m optical fiber to a remote optical probe.

The second technique, under development in-house at NASA Lewis, uses a high-resolution Fabry-Perot interferometer to spectrally resolve the Doppler-broadened, Rayleigh-scattered light. The width and shape of the spectrum are determined by the velocity distribution of the gas molecules.

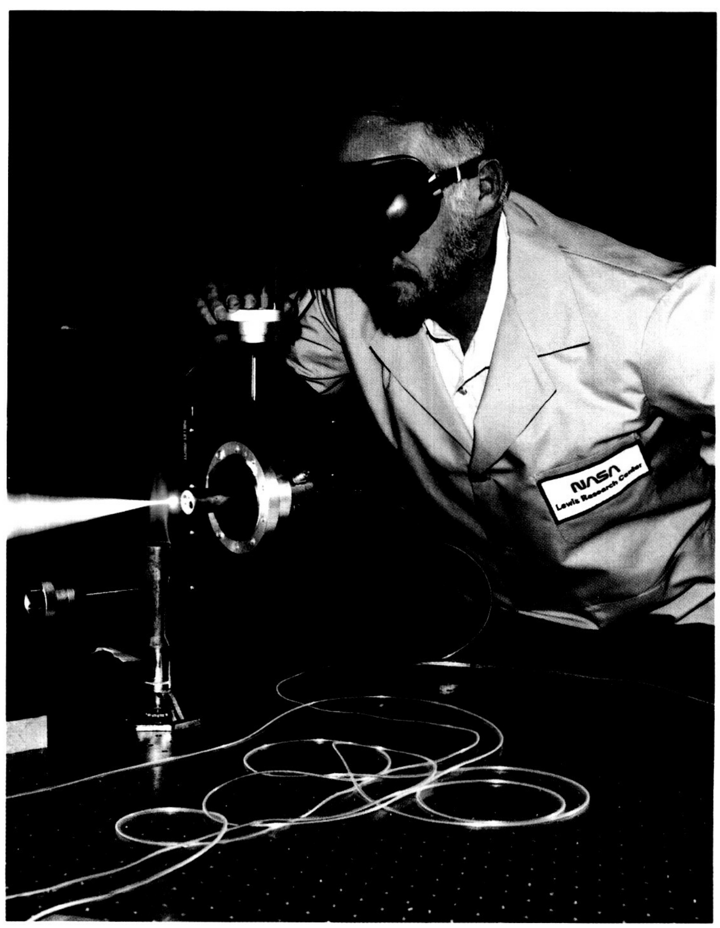
For low densities the spectrum is Gaussian and the gas temperature is proportional to the square root of the spectral width. For high densities the molecular motions are correlated and the spectrum can be described as the scattering of light from thermally induced acoustic waves. A laboratory experiment conducted in nitrogen at normal pressure and temperature (a low-density case) demonstrated an accuracy of about 6 K.

A technique for measuring gas density and temperature over a two-dimensional region is also being investigated for use in microgravity experiments. A laser sheet will illuminate the region of interest, and the Rayleigh-scattered light will be imaged through a planar Fabry-Perot interferometer onto a low-light-level video camera. The circular fringe pattern contains information about the gas temperature (via the fringe broadening) and the gas density (via the peak intensity of the fringes).

Bibliography

Annen, K.; and Joklik, R.: Final Report on the Development of a Rayleigh Scattering Diagnostic for Density and Temperature Measurements. Aerodyne Products Corp., Report 7907-00, 1987.

Lewis contact: Dr. Richard G. Seasholtz, (216) 433-3754
Headquarters program office: OAST



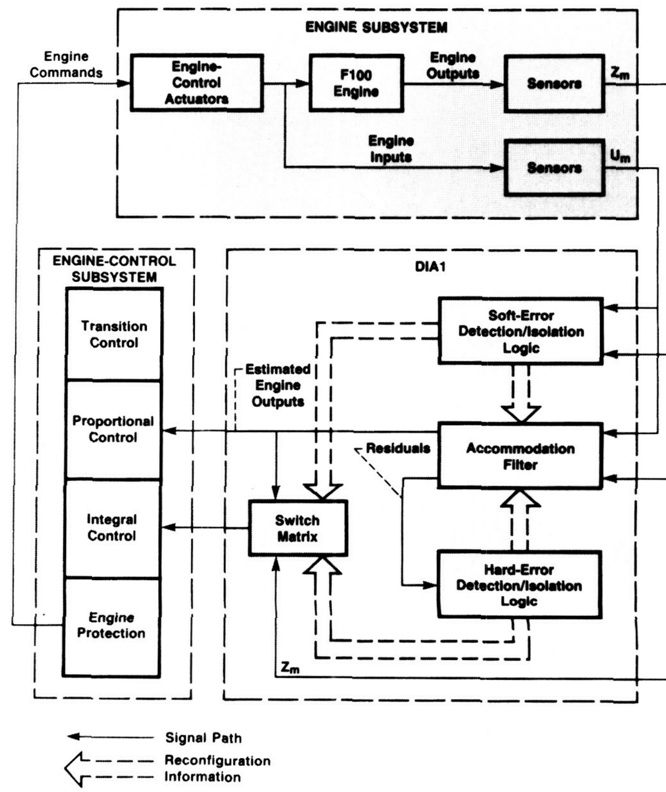
Copper-vapor laser Rayleigh scattering diagnostic

R&D 100

DIA1—A Sensor Failure Accommodator

The DIA1 is a microprocessor-based system that detects, isolates, and accommodates sensor failures in control systems. The DIA1 uses analytical redundancy and a detailed mathematical model of the process to interrelate the "normal" readings of different sensors. Then the DIA1 determines whether the indication of a given sensor is consistent with those of the other sensors, within prescribed limits.

The DIA1 algorithm consists of three elements: logic for the detection of hard failures, logic for the detection of soft failures, and the accommodation filter, which contains the mathematical engine model and produces the estimates of the process outputs. Hard failures are large out-of-range readings or bias errors that occur suddenly. These are relatively easy to detect via sudden large differences between the accommodation filter outputs and the sensor readings. Soft failures are small bias errors or drift errors that accumulate slowly and are more difficult to detect. The soft-error-detection logic includes one normal-mode filter and multiple failure-mode-hypothesis filters.



Flow chart of DIA1 sensor failure accommodator

These filters continuously track the sensor readings, searching for erroneous values. DIA1 performance is enhanced by an adaptive error threshold that is small during quiescent operation but increases during commanded transients of process operation. This adaption maintains high detection sensitivity while preventing false soft-error alarms. Accommodation is achieved by reconfiguring the accommodation filter to remove erroneous sensor information.

For ultrareliable controller designs, sensor failures (sensors are typically the least reliable components in these control systems) must be detected and accommodated. Current full-authority digital controllers for high-performance gas turbine engines in military and commercial aircraft rely on redundant feedback sensors as well as simple engine models and simple algorithms to detect and accommodate sensor failures. The DIA1, however uses a highly accurate and detailed model and a sophisticated algorithm that improves control system reliability without the additional cost of hardware redundancy.

The DIA1 is the only demonstrated (by both simulation and physical testing on a full-scale turbofan engine) system that detects both hard and soft sensor failures without hardware redundancy. The DIA1 allows continued full-range system performance after a single sensor failure and allows continued system performance after multiple sensor failures up to and including the loss of all feedback sensors. The technology is broadly applicable to feedback

control systems where high performance and high reliability are important requirements, such as gas turbine engines, rocket engines, process control systems, and space station power control systems.

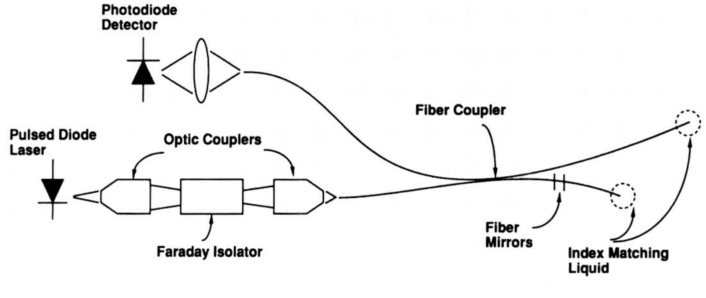
Research & Development magazine has selected the DIA1 to receive an R&D 100 award as one of the most significant technical developments of 1988.

Lewis contacts: Dr. Walter C. Merrill, (216) 433–6328; John C. DeLaat, (216) 433–3744
Headquarters program office: OAST

Embedded Fiber Optic Sensors

A critical need in advanced air and space vehicles is monitoring the integrity and performance of structural components. Embedded, multiplexed fiber optic sensors will enable in-situ, high-resolution measurements of structural parameters. Sensors embedded at the time of manufacture will provide information regarding the structure's environment from fabrication through assembly, test, and flight. Fiber optic sensors are ideally suited for this application, since they are lightweight, compact, rugged, and immune to electromagnetic interference.
The sensors consist of an optical fiber with a series of internal mirrors. In fabrication the fiber is cleaved, a thin semireflecting coating is sputtered onto the cleaved surface, and then the fibers are reconnected by fusion splicing. A pair of mirrors serve as a Fabry-Perot interferometer. These interferometers can be configured to measure strain, torque, pressure, temperature, impacts, leakage, or vibration. By monitoring reflected interference patterns, the signals from a number of distributed sensors along the length of a single fiber can be multiplexed by using only one light source and one photodetector.

NASA Lewis is supporting research to develop embedded-sensor technology. Under a grant to Texas A&M University, sensors to measure temperature, strain, and vibration are being developed, along with the multiplexing and embedding processes. To date, a temperature/strain sensor has been demonstrated, with the temperature sensor cycled between −200 and 1050 °C. The sensor has successfully been embedded into a graphite composite. During the embedding process the sensor underwent no apparent degradation and the strength of the composite was only minimally affected. This technology, when incorporated into a vehicle health-monitoring system, could improve safety, reliability, and cost effectiveness.



Optical configuration for embedded sensors

Lewis contact: George C. Madzsar, (216) 433–2421
Headquarters program office: OAST

Space Electronics

Monolithic Microwave Integrated Circuit, Gallium Arsenide Switch Matrix

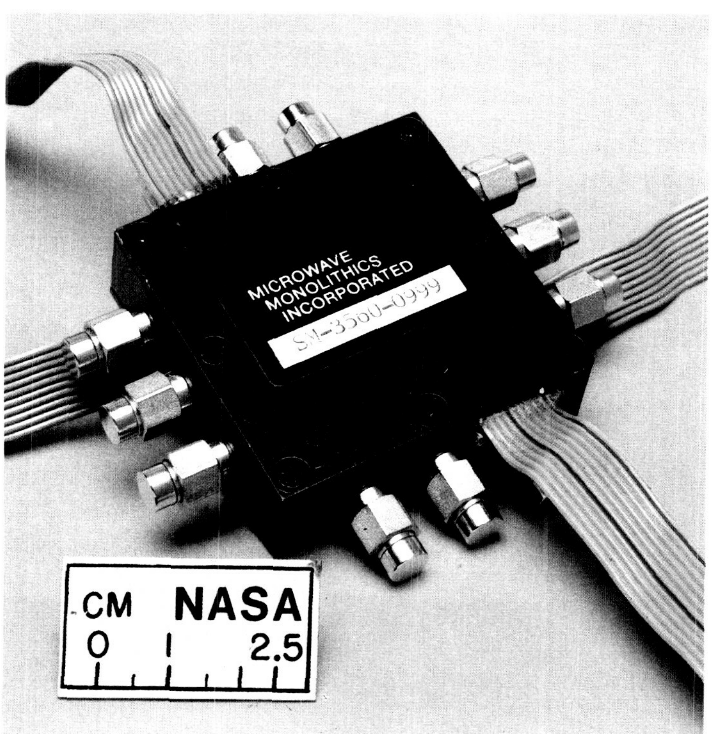
ORIGINAL PAGE
COLOR PHOTOGRAPH

In recent years NASA Lewis has sponsored the development of microwave switch matrices for use in satellite-switched, time-division multiple access communications systems. Present day designs rely on advanced hybrid microwave integrated circuits to build switch matrices such as the one to be flown on NASA's Advanced Communications Technology Satellite (ACTS). Through the Small Business Innovation Research Program a contract was awarded to Microwave Monolithics, Inc., to develop the next generation of switch matrix technology.

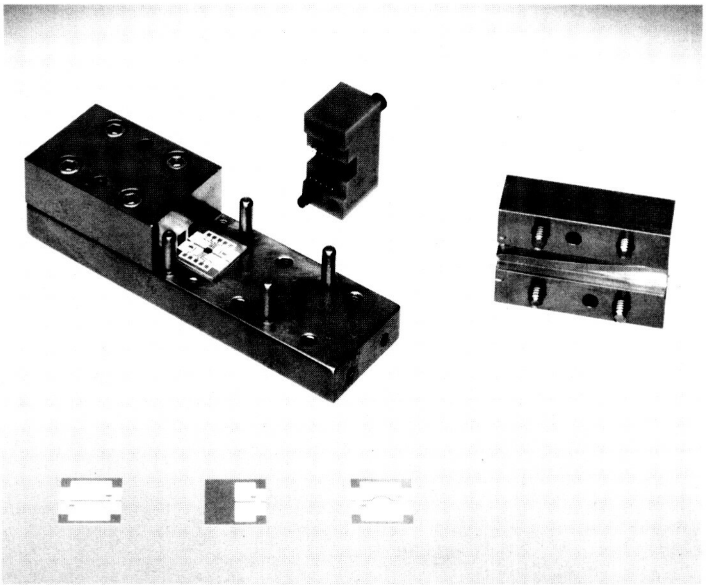
A 3×3 (3 input by 3 output) microwave crossbar switch matrix operating over 3.5 to 6.0 GHz has been fabricated in gallium arsenide by using monolithic microwave integrated circuits (MMIC's). The primary function of the MMIC GaAs switch matrix is to perform simultaneous high-speed switching and routing of multiple microwave signals without interference between channels. A significant feature of the MMIC switch matrix is the large-scale integration of many GaAs field-effect transistor switches in close proximity on a single chip while keeping isolation high for minimal channel-to-channel crosstalk. Breakthrough performance in isolation has been obtained (<60 dB at 6 GHz).

The monolithic implementation of the switch matrix is attractive for future communications satellites, primarily for its low power consumption, reduced size and weight, and potentially lower costs. A modular design concept coupled with a unique packaging approach will allow for the cascading of smaller switch submodules into larger MMIC switch matrices with little or no performance degradation. Plans are under way to develop a 6×6 switch matrix with buffer amplification to provide an overall 0-dB insertion loss and with integrated control electronics compatible with a standard computer interface.

Lewis contact: Gene Fujikawa, (216) 433-3495
Headquarters program office: OSSA



MMIC gallium arsenide switch matrix



Universal test fixture

The integrated-circuit test fixture and calibration software are the subjects of a technical publication, and a patent application has been submitted.

Bibliography

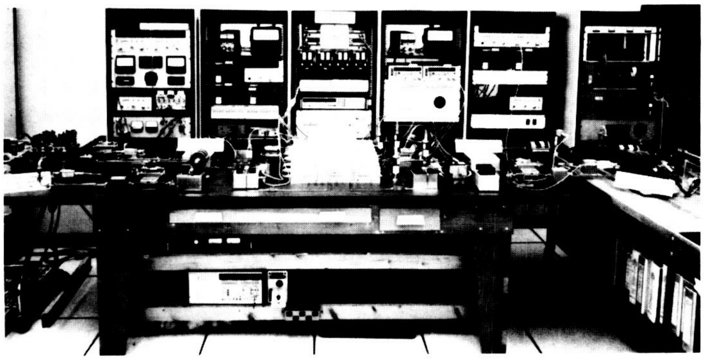
Romanofsky, Robert R.; and Shalkhauser, Kurt A.: Universal Test Fixture for Monolithic Millimeter-Wave Integrated Circuits Calibrated With an Augmented TRD Algorithm. NASA TP-2875, 1988.

Lewis contacts: Kurt A. Shalkhauser, (216) 433-3452; Robert R. Romanofsky, (216) 433-3507
Headquarters program offices: OAST and OSSA

Universal Test Fixture for Millimeter-Wave Integrated Circuits

Over the last several years NASA Lewis has been pursuing advanced solid-state technology development beyond 26.5 GHz in order to exploit the benefits of higher frequencies for space communications. Device characterization techniques at these frequencies, however, have not been adequately established. In response to this need a novel fixturing technique for characterizing microwave and millimeter-wave solid-state devices has been developed as part of an ongoing in-house effort.

High-frequency integrated circuits must be mounted in a fixture that connects the device to the test instrumentation. The fixture often masks the true characteristics of the device under test. This limitation was overcome by using microstrip calibration standards and a mathematical routine to extract the actual device data. A cosine-tapered ridge guide transition is used to couple the device to the instrumentation. The taper width and profile have been analytically determined for maximum bandwidth and minimum insertion loss. Contact is achieved by a critical interference fit rather than the conventional bonding. Power is supplied to the test device through a biasing module that incorporates 10 spring-loaded probe contacts. Thus a wide variety of solid-state devices can be tested in an accurate, rapid, nondestructive fashion. Furthermore, only one set of calibration standards is required regardless of the device geometry.



SITE test facility

Systems Integration, Test, and Evaluation Project

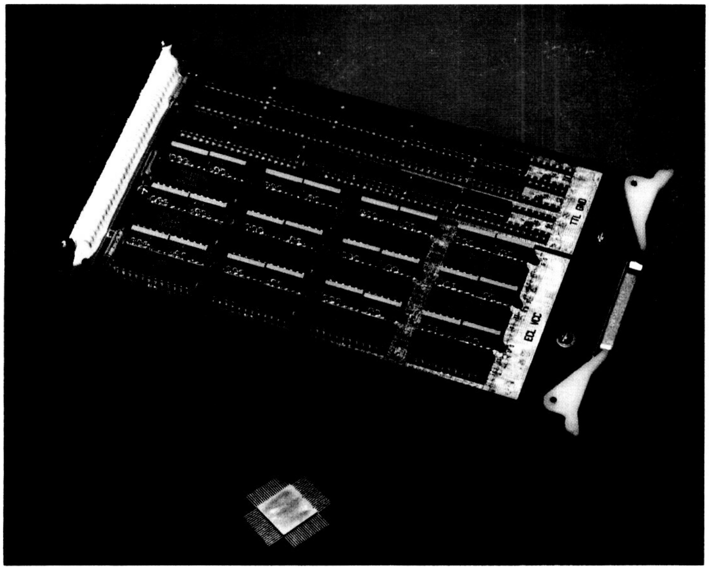
The Systems Integration, Test, and Evaluation (SITE) Project uses a unique, laboratory-based test facility to evaluate advanced satellite communications system technology. The test facility, designed and built at NASA Lewis, consists of a simulated satellite transponder integrated with high-data-rate digital ground terminals to present an accurate model of a satellite communications system. The test facility's flexibility allows evaluation of advanced system design concepts, component performance, hardware and software, and networking and control technology. System experiments such as performance, degradation due to interference, or signal attenuation effects due to rain are also performed. Major components of the facility such as high-power amplifiers and high-data-rate modems are the result of hardware development contracts. The digital ground terminals and transponder integration are entirely in-house efforts.

The first phase of the SITE project established a complete simulated satellite link. An extensive test program has evaluated the performance of numerous proof-of-concept components in a real digital data environment. The results of these tests have been reported at six conferences and in 14 publications. The second phase of the project, now under way, will expand the test facility into a multiple ground terminal network operating in a time-division multiple access format, including a radiative (30 and 20 GHz) link to a remote terminal.

In addition to the general communications research capabilities of SITE, the project also includes several specific thrusts that support current and future NASA programs. In support of the ACTS Program the SITE Project provides experimental data that assist the ACTS flight and ground systems. The high-burst-rate link evaluation ground terminal development also relies heavily on SITE facilities and expertise. Another major SITE effort is the development of low-cost ground terminals for satellite communications applications.

In the development of low-cost ground terminal systems and in support of SITE digital electronic systems, application-specific, integrated-circuit (ASIC) facilities have been implemented that will provide the state-of-the-art, computer-assisted-design features required in developing high-performance digital systems. The ASIC design capabilities are unique at Lewis and offer the increased performance and reliability in digital electronics necessary for the development of future space communications, power, and propulsion applications. Ongoing expansion of the ASIC facilities will extend current capabilities into additional user support and increased design and analysis capabilities.

Lewis contacts: Monty Andro, (216) 433–3492; Robert J. Kerczewski, (216) 433–3434
Headquarters program office: OSSA



Reduction in size of 64-bit converter module

Gallium Arsenide S/P–P/S Interface Technology Development

The gallium arsenide S/P–P/S interface technology development initiative demonstrated the ability to develop very high-speed, low-power, large-scale integrated digital circuits in gallium arsenide (GaAs), a state-of-the-art material. The yield was very respectable, exceeding 50 percent. Very high-speed digital circuits have become commercially available in GaAs, but not in the configuration and with the low power demonstrated here.

Honeywell, Inc., Sensors and Signal Processing Laboratory, under contract to NASA Lewis, developed a family of 16-, 32-, and 64-bit serial-to-parallel (S/P) and parallel-to-serial (P/S) converter modules to demonstrate this technology. The approach used was an enhancement/depletion-mode, self-aligned-gate, metal semiconductor field-effect transistor (MESFET) technology.

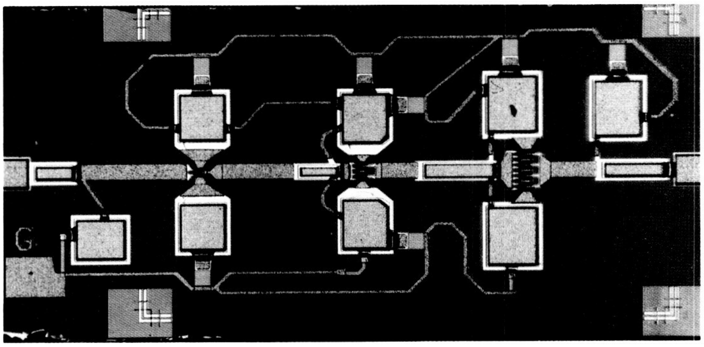
The program goals were to achieve clock rates of 550 MHz at a power dissipation of 250 mW. The program was completed successfully, exceeding the goals of the contract by demonstrating clock rates of 700 MHz at a power dissipation of 250 mW.

Lewis contact: Monty Andro, (216) 433–3492
Headquarters program office: OSSA

Monolithic Microwave Power Amplifiers

NASA Lewis is developing a number of advanced monolithic microwave integrated circuits (MMIC's) for use as power amplifiers in communications systems. The primary advantages of such circuitry are its smaller size and lower weight than solid-state technologies using discrete devices or tube technologies. Major problems with solid-state technology have been the power levels that can be generated and the power-added efficiency that is achievable. The Lewis program attempts to demonstrate the feasibility of MMIC technology at 15 and 32 GHz, to improve the state-of-the-art power output and efficiency of such devices, and to facilitate the insertion of such devices into NASA missions. The MMIC work is an ongoing program begin carried out under contract, with Texas Instruments performing the work described here.

Within the last year major advances have been achieved in the power output and efficiency available in MMIC amplifiers. Recently developed materials such as AlGaAs and InGaAs, in conjunction with the more mature GaAs, have been used to develop discrete devices at 14 GHz. The output power density is 0.7 W/mm of gate width and the efficiency is 40


Three-stage amplifier

percent. Since practical devices can be fabricated with total gate peripheries of several millimeters, the present development can be realistically expected to lead to microwave transistors with an output power of 4 W. In addition, three stages of such devices have been cascaded to produce high-gain, high-power amplifiers. By using newly developed nonlinear modeling and simulation techniques to design interstage matching networks, Texas Instruments fabricated and tested a three-stage, monolithic, variable-power amplifier. It exhibits 20 dB of gain, 0.9 W of power output, and 28 percent power-added efficiency. These amplifiers are intended for use in the space station multiple-access communications system. The development is being coordinated with NASA Johnson Space Center, and preliminary chips have been delivered there for environmental and subsystem evaluation.

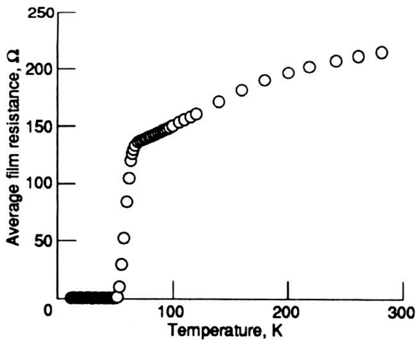
In work at 32 GHz transitions have been fabricated with an output power density of 0.8 W/mm and 42 percent power-added efficiency. This device, a 75-μm-wide modulation-doped, field-effect transistor (MODFET) with a double pseudomorphic structure, is based on InGaAs. Carriers are contributed from doped layers on each side of the conduction channel. The 42-percent efficiency achieved compares favorably with that available from the heavier, high-voltage vacuum tube power sources. In addition, many applications such as phased-array antennas with electronic beam-steering require multiple (< 100) small power sources with spatially combined outputs. Continuing work will focus on the use of such devices in a multistage amplifier with 15 to 18 dB of power gain. The devices developed under this effort are targeted for use in the deep-space network communications system. To this end, the program is coordinated with personnel from the Jet Propulsion Laboratory, and preliminary versions of the developmental circuits have been supplied to them for evaluation in a breadboard phased-array antenna. Candidates for application include a Ka-band demonstration beacon aboard the comet rendezvous and flyby (CRAF) mission, a phased-array communications antenna for the Cassini spacecraft, and a communications antenna for a Mars rover vehicle.

Lewis contacts: Robert R. Romanofsky, (216) 433-3407; Dr. Edward J. Haugland, (216) 433-3516
Headquarters program offices: OAST and OSSA

Superconducting Materials in Microwave Electronics

In the last year NASA Lewis has undertaken a program to demonstrate the usefulness of newly discovered high-temperature (77 K) superconducting materials in microwave electronics applications. The program has had as its objective the fabrication of passive microwave circuits from thin films of yttrium barium copper oxide (YBaCuO), a ceramic material that exhibits superconductivity at liquid-nitrogen temperatures.

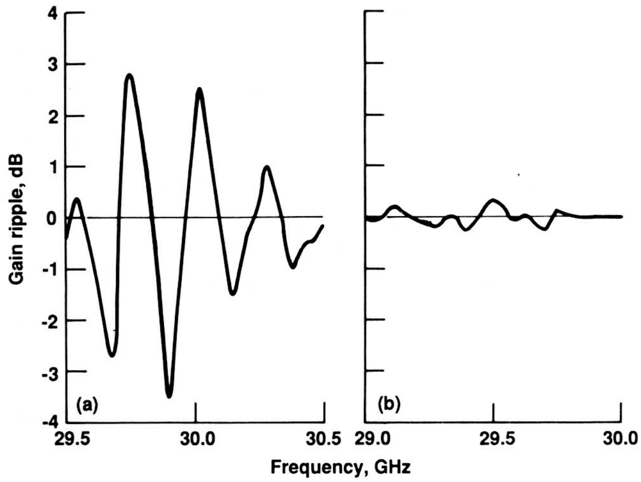
As a first step in this development it was necessary to investigate and establish mechanisms for the deposition of thin films on appropriate substrates. For this purpose cooperative agreements were established with a number of institutions including the Naval Research Laboratory, Ohio State University, Oberlin College, the University of Cincinnati, the University of Nebraska, Bell Laboratories, and TRW Electronic Systems Division. As a result of these agreements thin superconducting films have been obtained on substrates of alumina, magnesium oxide, strontium titanate, and sapphire. In conjunction with these activities an in-house program is focusing on optimizing annealing procedures, characterizing films, developing techniques for patterning films, and developing techniques for testing radiofrequency circuits at cryogenic temperatures. Characterization activities include critical temperature measurement, critical current measurement at magnetic fields up to 140,000 G at liquid-helium temperatures, and radiofrequency conductance measurements. Within the next 6 months a facility to do magnetic susceptibility measurements will come on-line.



Film resistance versus temperature of thin superconducting film

To date, a "meander-line" pattern has been produced in YBaCuO. This represents the simplest example of a microwave circuit and will be used to provide critical information in evaluating high-temperature superconducting materials as a microwave medium. Cooperative in-house efforts have also resulted in the production of thick superconducting films of YBaCuO through screen-printing techniques, which are also amenable to the production of patterns and passive microwave circuits at lower frequencies (1 to 10 GHz). These films will be characterized and used in simple radiofrequency circuits in the same manner as the thin films. It is envisioned that once the advantages of high-temperature superconducting materials have been successfully demonstrated in microwave applications, a development contract will be issued to utilize them in a full monolithic integrated circuit development.

Lewis contact: Dr. Regis F. Leonard, (216) 433-3500
Headquarters program office: OAST



Reduction of high-power TWT distortion: (a) conventional TWT; (b) low-distortion TWT

Low-Distortion, 29-GHz Traveling-Wave Tube for Ground Terminal Applications

Methods of reducing signal distortion in coupled-cavity, traveling-wave tubes (TWT's) are being studied by Hughes Aircraft Company under an ongoing research and development contract with NASA Lewis. The five 29-GHz, 400-W TWT's being fabricated have power and frequency characteristics compatible with the ground station transmitter for the Advanced Communications Technology Satellite (ACTS).

The TWT's in this program are different from conventional coupled-cavity TWT's in that the circuit cavities do not have ferrules. (Ferrules are inner rings that increase interaction between the circuit electric field and the electron beam.) Although the ferruleless circuit needs to be longer to achieve the gain of a ferrule circuit, it is considerably less expensive to machine, has better dimensional tolerances, and produces weaker distortion-inducing backward waves. The first two such TWT's have been built and tested. Results indicate that the most important factor in reducing the small signal gain ripple, which causes signal distortion, is the design of a good output match. Excellent low-reflection matches were obtained in both TWT's. This led the way to outstanding low-distortion characteristics. The small signal gain ripple for both TWT's was less than 0.5 dB, which is a considerable improvement over any known high-power TWT at this frequency. When small signal gain ripple over the 1-GHz bandwidth of the second TWT was compared with that for a typical high-power, coupled-cavity TWT at a similar frequency, the reduction in ripple from 6 to 0.4 dB was quite evident.

The third TWT has just been fabricated and is almost ready for testing. It has a different design in that the cavities are slightly longer. Theoretically this will provide for more destructive interference of the backward wave and thus decrease the feedback responsible for distortion. The fourth and fifth TWT's will employ NASA-designed velocity tapers to optimize efficiency.

Bibliography

Shalkhauser, K.A.: Bit-Error-Rate Testing of High-Power 30 GHz Traveling-Wave Tubes for Ground-Terminal Applications. IEEE Trans. Electron Devices, vol. ED–34, no. 12, pt. 2, Dec. 1987, pp. 2625–2633.

Lewis contact: Dr. Jeffrey D. Wilson, (216) 433–3513
Headquarters program office: OAST

Submillimeter-Wavelength Backward-Wave Oscillators

In a cooperative effort with Lincoln Laboratories and The University of Utah, NASA Lewis is developing the technology for a series of backward-wave oscillators (BWO's) in the frequency range 500 to 2000 GHz. These electron beam tubes will be used as local oscillators in heterodyne receivers and spectrometers to study planetary atmospheres. Because tube dimensions scale with wavelength, traditional methods cannot be used to machine the slow-wave structure of the BWO. A photolithographic method was thus developed to etch the circuit onto a diamond substrate. Diamond has five times the thermal conductivity of copper and will provide superior heat transfer. Other innovations include a high-conversion-efficiency circuit (the interdigital line) and research on long-lived cathodes. This will result in longer lifetimes, less thermal loading of the circuit, and smaller magnetic focusing fields. Because the period of the etched circuit can be very small, lower beam voltages are possible.

Local oscillator noise is a major consideration in heterodyne receiver design. Transverse energy in the electron beam is probably a major source of BWO noise, and transverse energy increases with beam compression. The tubes presently being built should offer a reduction in noise because the gun is designed for only moderate beam compression.

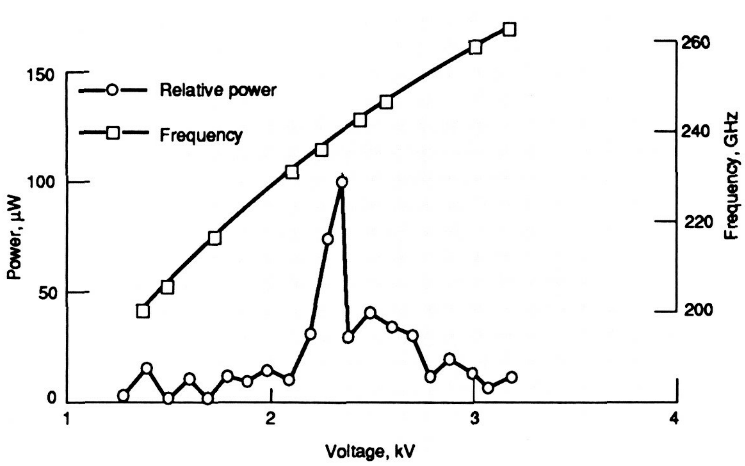
A 200- to 260-GHz prototype BWO was built and tested. Oscillations over the frequency range 200 to 265 GHz were immediately observed. The output power was estimated to be in the 50- to 100-μW range, but the output coupler was not optimized. A new output coupler has been designed and incorporated into the interdigital line circuit. This coupler will enable quasi-optical coupling with a sapphire hyper-hemispherical lens system. Two new circuits have been fabricated at Lincoln Laboratories. One circuit was sent to The University of Utah for incorporation into their prototype BWO; and the other will be used at Lewis in our planned experiment. It is expected that the new output coupler will result in output powers in the milliwatt range.

Bibliography

Efremow, N.N., et al.: Ion-Beam Assisted Etching of Diamond. J. Vac. Sci. Technol. B, vol. 3, no. 1, Jan.-Feb. 1985, pp. 416–418.

Barnett, L.R., et al.:Submillimeter-Wave BWO's. International Electron Devices Meeting (IEDM) Technical Digest, IEEE, Piscataway, NJ, 1985, pp. 364–365.

Lewis contact: Norbert Stankiewicz, (216) 433-3674
Headquarters program office: OAST



Relative power and frequency of submillimeter-wavelength backward-wave oscillator

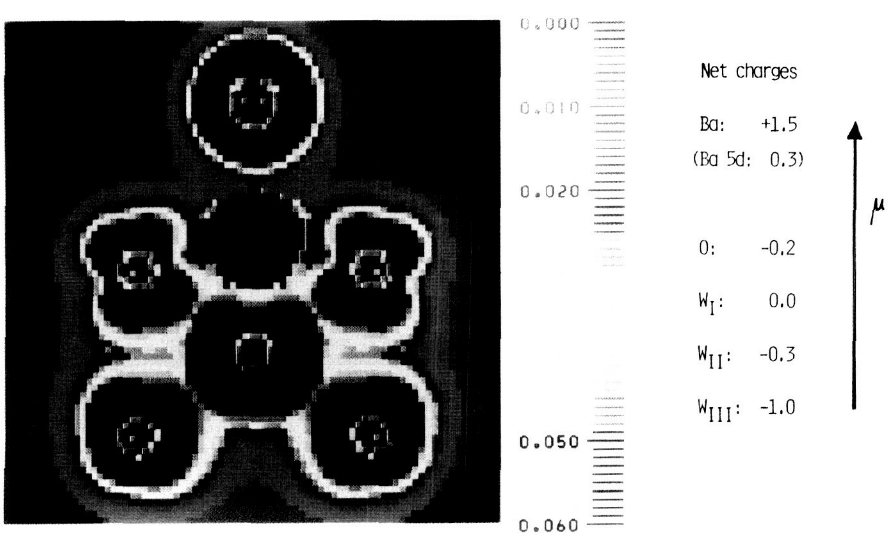
Theoretical Studies of Cathode Surfaces

NASA Lewis has long been a leader in the development of microwave tubes for communications and other space applications. Advances in the technology today are toward higher frequencies and ofttimes higher output power. These tube requirements demand that the cathode, which is used for the electron source, be capable of higher current densities and simultaneous long operating life. In addition, there is the never-ending quest for lower cathode operating temperatures, the benefits of which include reduced constraints on device design, improved cathode reliability, and longer cathode life.

The cathode type most commonly used for modern tube applications is the barium dispenser thermionic cathode. Its electron-emitting surface is a very complex chemical and thermodynamic system. It typically consists of barium (Ba) and oxygen (O) interacting with a refractory metal or alloy such as tungsten (W), osmium (Os), or tungsten-osmium (W-Os). This interaction is the cause of the characteristically large reduction in electronic work function. The various refractory metals display significantly different degrees of emission current enhancement, with W-Os showing the largest. Although barium dispenser cathode surfaces have been extensively investigated experimentally in recent years, the basic mechanism responsible for emission enhancement has evaded an accurate description at the atomic level. A thorough understanding of this mechanism, which is related to the localized electronic character of the Ba-O-metal chemical bonds, is considered important to the development of better-performing cathodes.

State-of-the-art computational methods of theoretical quantum chemistry are now being successfully applied to ongoing studies of the physics and chemistry of barium dispenser cathode surfaces. The work is being performed on-site, under contract, by Analatom Inc. on the Lewis Cray computer. The principal quantum chemical method used is the relativistic X-alpha, in which the cathode is modeled by a many-electron cluster of atoms. The wave equation of each electron in the cluster is solved self-consistently in the average electrostatic field of all the other electrons for the wave function and the electron energy. Some of the clusters contained more than 1000 electrons, which required that major improvements in computational procedures and efficiency be made in order to obtain accurate results.

Among the electron properties calculated are atomic orbital energy levels, valence electron energy spectra, electron charge distributions, and barium-substrate



BaO/W$_9$ electron density

electronic dipole moments. The last can be related to work function and barium-substrate binding energies. The cluster calculations have produced quantitative results that provide, for the first time, detailed knowledge of the electronic nature of the barium chemical bonds and insight into the cause of the observed differences in electron emission enhancement. The theoretical results are consistent with all available experimental data and the observed behavior of these cathodes. For the first time we can now look directly at the rearrangement of valence electrons associated with the adsorption of barium and oxygen on the metal surfaces characteristic of real cathodes.

These theoretical studies have greatly advanced our knowledge and understanding of the physics and chemistry of barium dispenser thermionic cathodes. The results have been received with enthusiasm throughout the cathode community, especially by the specialists and tube engineers who have been pondering the mysteries of cathode operation over the years.

Bibliography

Mueller, W: A Quantum Chemical Study of BaO/W Cathode Surfaces. J. Vac. Sci. Technol. A, vol. 6, no. 3, May-June 1988, pp. 1072–1073.

Mueller, W.: Theoretical Study of Cathode Surfaces. NASA CR–182166, 1988.

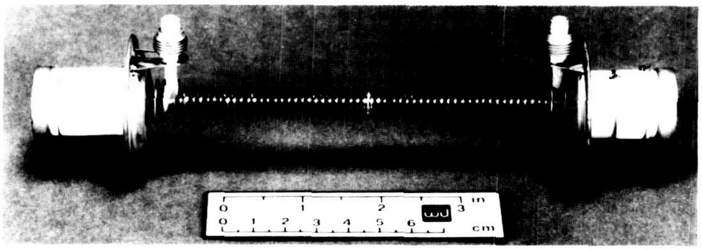
Mueller, W.: Electronic Structure of BaO/W Cathode Surfaces. Submitted to IEEE Trans. Electron Devices.

Lewis contact: Edwin G. Wintucky, (216) 433–3510
Headquarters program office: OAST

High-Efficiency Traveling-Wave Tube With Dynamic Velocity Taper

From the expected success of current research on traveling-wave tube (TWT) efficiency enhancement, it is reasonable to predict the development of a new class of very high-efficiency amplifiers for future space communications applications. A contract has been let to Watkins-Johnson to fabricate, test, and deliver six TWT's. These will serve as experimental verification of Lewis' computer predictions for novel dynamic velocity taper (DVT) circuits and as test vehicles for multistage depressed collectors (MDC's) with electrodes designed to minimize secondary electron emission. These tubes are designed for 8.4 GHz, the frequency currently used in the deep-space network. The 20-W power output was chosen in consultation with the Jet Propulsion Laboratory (JPL).

Three of the TWT's feature an output helix-section DVT designed for maximum gain, and the other three a DVT designed for minimum signal distortion and phase shift. Four of the six sets of MDC electrodes are to be treated at Lewis with in-house-developed ion-texturing processes to enhance MDC efficiency by reducing surface secondary-electron emission. The DVT and MDC electrical designs were performed at Lewis and supplied to the contractor for fabrication. Objectives of the program include achieving an overall TWT efficiency of a least 55



High-efficiency TWT with dynamic velocity taper

percent, a saturated gain of 48 dB, and a design life of 10 years. Tests at Watkins-Johnson with the first TWT's (with undepressed collectors) indicate good agreement between predicted and measured radiofrequency efficiencies with as high as 30 percent improvement in radiofrequency efficiency over conventional helix designs.

Two complete sets of MDC modules (eight pieces in all) with high-purity isotropic graphite electrodes have been ion textured at Lewis and returned toWatkins-Johnson for assembly and mating with a TWT for testing. Two additional sets of MDC modules with copper electrodes are now being similarly surface treated at Lewis and will shortly be returned to the contractor as well.

The transfer of this technology to applications supporting the exploration of deep space has already begun. By coincidence, Watkins-Johnson is also under contract to General Electric/RCA to build the 44-W, 84-GHz TWT's for the JPL Mars observer mission. When Watkins-Johnson was unable to meet the mission requirements for TWT efficiency, they requested Lewis' assistance in the design of a DVT circuit. The Lewis design permitted Watkins-Johnson to exceed specifications, providing direct technology transfer from the OAST research program to this OSSA mission.

Consultations are continuing between Lewis and JPL regarding application of this efficiency enhancement technology to 32-GHz transmitters for the Cassini and Mars Rover missions. JPL is presently reviewing a draft statement of work for a TWT amplifier for use on Cassini.

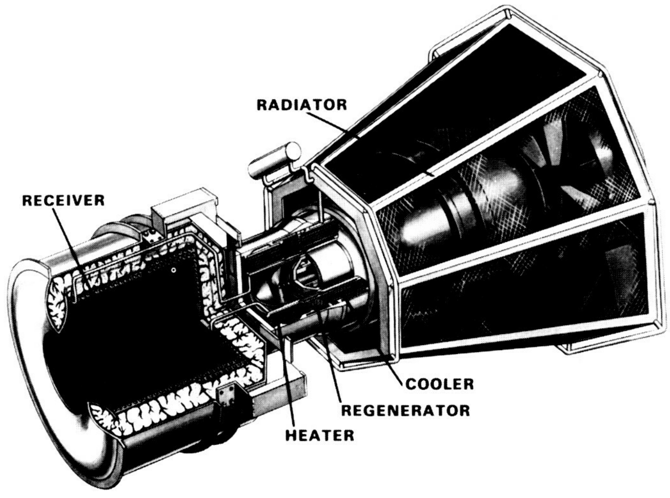
Bibliography

Curren, A.N.: High-Efficiency Helical Traveling-Wave Tube With Dynamic Velocity Taper and Advanced Multistage Depressed Collector. IEEE International Electron Devices Meeting (IEDM) Technical Digest, IEEE, Piscataway, NJ, 1987, pp. 473–476.

Lewis contact: Arthur N. Curren, (216) 433–3519
Headquarters program office: OAST

Power Generation

Advanced Stirling Conversion System



Conceptualized free-piston Stirling engine

The Stirling engine has been identified by the U.S. Department of Energy (DOE) and Sandia National Laboratories Albuquerque (SNLA) as the most promising heat engine for conversion of solar energy to electric power. Studies have shown that the Stirling conversion system has the potential to meet the DOE long-term performance and cost goals. Lewis manages the Advanced Stirling Conversion System Program for DOE/SNLA. The free-piston Stirling engine has been chosen because of its potential to provide high reliability with long life, high cycle efficiency, and low production costs.

Two conceptual design studies, completed in 1987, featured the free-piston Stirling engine integrated with a liquid-metal receiver operating at 700 °C. The prime contractors were Mechanical Technology Inc. (MTI) and Stirling Technology Company (STC). MTI's design uses a free-piston Stirling engine with a linear alternator; STC's design uses a free-piston Stirling engine with hydraulic output coupled to a rotary alternator. Independent studies have shown that both the MTI and STC conceptual designs would probably meet the DOE cost goals if produced in quantities of 10,000 units per year. These single-engine, stand-alone conceptual designs can provide nominally 25 kW of electric power to a utility grid while operating on solar energy from an 11-m-diameter parabolic dish concentrator. The system consists of a solar energy receiver, a reflux boiler heat transport system, a free-piston Stirling engine, an engine heat rejection system, and an alternator or generator coupled either directly or indirectly to the engine and to the utility grid with the appropriate controls and power conditioning.

A follow-on effort has begun to complete the design and to fabricate, assemble, and test an advanced Stirling conversion system. The system will feature the free-piston Stirling engine, will use existing technology, and will emphasize manufacturability throughout the effort. Delivery of a complete system to the SNLA test facility in Albuquerque, New Mexico, is expected in 1991. Completion of the design will provide NASA an opportunity to ground test a free-piston Stirling conversion system, which has the potential to be a solar dynamic system for space. Plans are to evaluate additional advanced Stirling conversion systems operating on the electric grid in order to identify reliability and life issues.

Lewis contacts: Richard K. Shaltens, (216) 433–6138; Jeffry G. Schreiber, (216) 433–6144
Fund source: DOE

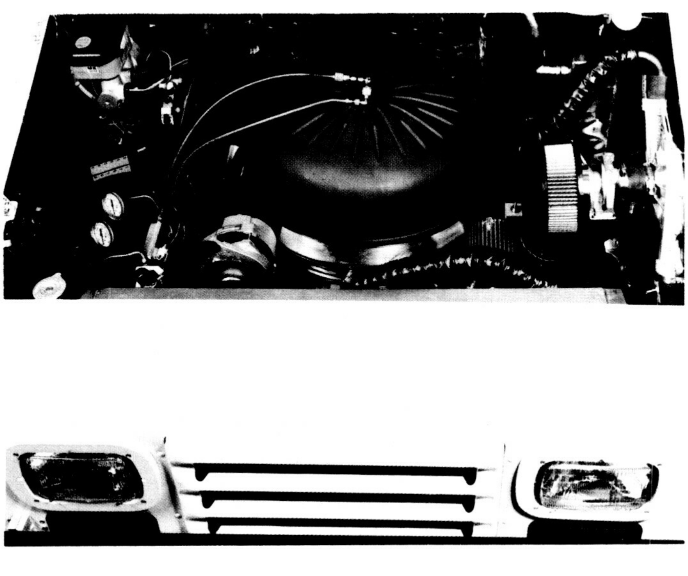
Automotive Stirling Engine

An automotive Stirling engine is being developed under a U.S. Department of Energy (DOE) program to develop the technology for an alternative automotive powerplant. Lewis manages the Automotive Stirling Engine (ASE) Program for the DOE. The prime contractor is Mechanical Technology Inc. The ASE Program is scheduled for completion this year with a demonstration of program objectives.

The first-generation engine (Mod I) has completed development and seven Mod I engines have accumulated over 19,000 hr of testing including over 2000 hr in vehicle operation. Over 1000 hr were accumulated in evaluation of a Mod I-powered van at Langley Air Force Base, where it served regular duty on the flight line. Nearly 1000 hr and 15,000 miles of operation were recorded by a Mod I engine-powered pickup truck in service at Langley, Eglin, Randolph, and Offutt Air Force Bases and in transit between the bases. All driving was done by Air Force personnel. During this use the truck demonstrated a duty availability of over 95 percent and a hydrogen tank recharge interval of 6 days.

The technologies arrived at during development of the Mod I engine have been incorporated in a second-generation (Mod II) engine. Three engines have been built and over 1000 hr of development testing has been completed. One Mod II engine is now installed in a U.S. Postal Service long-life vehicle, and development testing is under way in preparation for demonstrating the ASE program goals in an Environmental Protection Agency-certified chassis dynamometer facility. Since last year the program has been changed to substitute the postal van for the Chevrolet Celebrity originally chosen for the demonstration. The change was made because interest in Stirling has diminished in the automotive industry and increased among light truck fleet users, in particular the U.S. Air Force and the U.S. Postal Service. Significant fuel economy improvement will be achieved, but it will be less than the program goal because of vehicle differences. Emissions and fuel adaptability should meet program goals.

Lewis contact: William A. Tomazic, (216) 433-6141
Headquarters program office: OAST



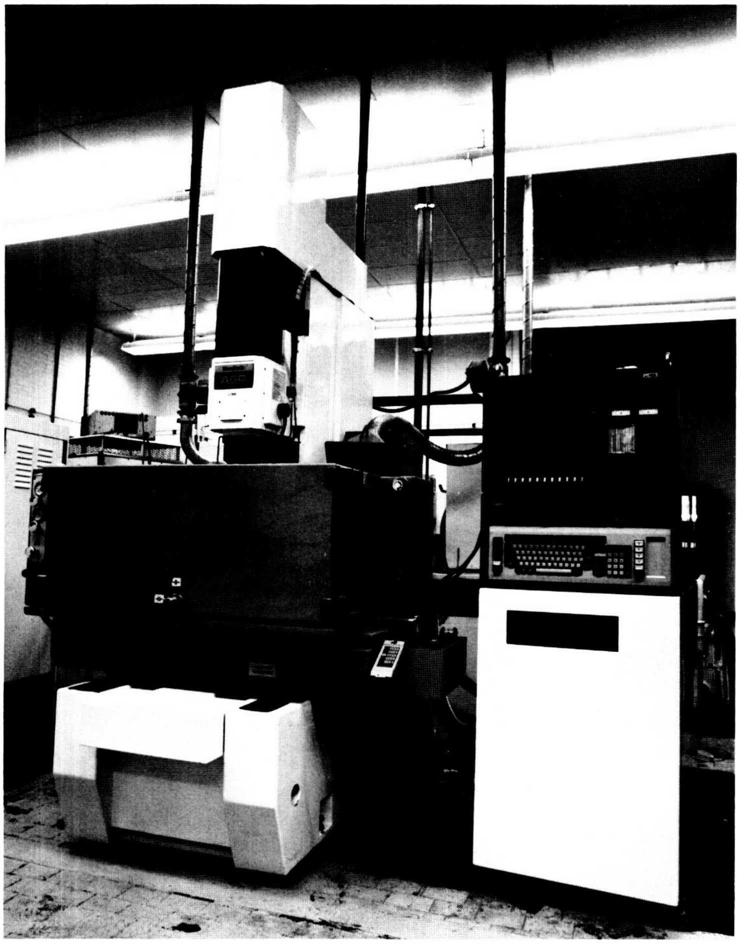
Stirling engine installed in van

Facility

New Machining Capability for Contouring Special Metal Materials and Shapes

The electrical discharge machine (EDM) provides a new machining capability for NASA Lewis. This vertical EDM machine has the contouring capabilities of a four-axis milling machine. It will machine hardened materials, automatically remachine its own electrodes, and compensate for the resultant changes in electrode size. Difficult geometries, such as internal and external threads, helical gears, splines, helixes, and undercut pockets are also possible.

The EDM deep-hole drilling machine is designed to produce very high-aspect-ratio holes (at least 250:1) in any electrically conductive material. An added benefit is the very high drilling speed. For example, only 45 sec are required to drill a 1-mm hole through 1 in. of 304 stainless steel. The uniqueness of this fabrication facility will greatly enhance Lewis' machining of special metal materials and shapes that support our materials science and technology programs.



Electrical discharge machine

Lewis contact: Gerald L. Matusik, (216) 433-2083
Headquarters program office: OAST


NASA

Aeropropulsion

Strategic Objectives

- To strengthen our position as the principal NASA center for the advancement of aeropropulsion technology that will significantly contribute to the continuing preeminence of U.S. civil and military aircraft.

- To become the nation's pathfinder in innovative aerospace propulsion research and technology.

1987 Collier Trophy Advanced Turboprop Project

The NASA/Industry Advanced Turboprop Team has produced a major achievement in aeronautics through the conception, development, and flight verification of advanced turboprop propulsion technology applicable to several new aircraft propulsion systems. This technology base provides for future commercial development of single-rotation and counterrotation turboprop propulsion systems that offer dramatic reductions in fuel usage and operating costs. They are expected to engender a new generation of subsonic transport aircraft for both civil and military uses.

The Collier Trophy

The initial propeller concepts for these advanced turboprop systems were generated in the mid-1970's in response to rapidly increasing fuel prices resulting from the initial OPEC oil embargo. Advanced propeller designs, involving thin, highly swept and twisted blades, emerged from cooperative research at NASA Lewis and Hamilton Standard. The feasibility of achieving major improvements in aerodynamic efficiency with these unique propellers operating at high subsonic speeds (Mach 0.8) was subsequently demonstrated in wind tunnel tests.

This led to a major NASA, industry, and university program to develop the related aerodynamic, structural, mechanical, and acoustics technologies required for future turboprop propulsion systems and to verify the potential performance improvements of these systems in ground and flight tests. The technical expertise of NASA's three aeronautical research centers (Ames, Langley, and Lewis) and more than 40 industry contract and university grant efforts were successfully employed in this program. The contracts and grants involved a broad cross section of the U.S. aeronautics community. This entire program was managed and integrated by NASA Lewis personnel.

The program reached fruition in 1987 with successful verification of technology readiness in three series of flight tests: (1) the NASA/General Electric/Boeing flight tests of the General Electric gearless counterrotating Unducted Fan (UDF) on a B-727 aircraft, (2) the NASA/Lockheed Propfan Test Assessment of a single-rotation advanced turboprop on a Gulfstream II aircraft, and (3) the General Electric/McDonnell Douglas flight tests of the UDF on an MD-80 aircraft. In addition, Pratt & Whitney and Allison have jointly conducted extensive ground tests of a geared counterrotating propfan propulsion system in preparation for flight tests on an MD-80 aircraft in early 1988.

These flight tests verified the readiness of this advanced turboprop propulsion technology for commercial engine systems development. Also, they demonstrated the potential for reducing fuel burn by 25 to 30 percent over future conventional turbofan engines with equivalent engine core technology. This reduction in fuel usage should lower direct operating costs of future transports by as much as 15 percent. As a result, several new engine and aircraft developments are being planned by the U.S. aeronautics industry to take full advantage of this major advance in aeropropulsion technology.

The Collier Trophy citation reads: "The NASA Lewis Research Center and the NASA/Industry Advanced Turboprop Team, for developing advanced turboprop propulsion technology for new fuel-efficient subsonic aircraft propulsion systems."

Lewis contact: G. Keith Sievers, (216) 433-3898
Headquarters program office: OAST

ORIGINAL PAGE
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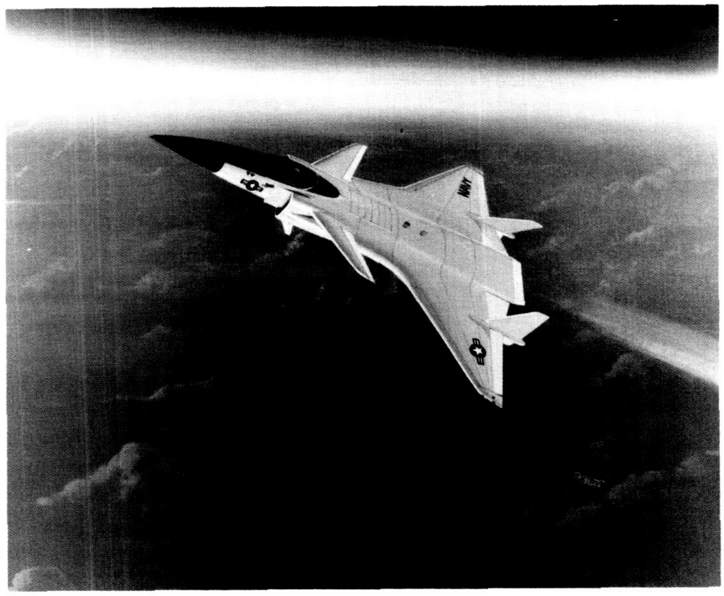
Supersonic Short Takeoff and Vertical Landing Aircraft Propulsion

Advanced propulsion has been recognized as the key technology for future high-performance military aircraft. Current fighter aircraft with short takeoff and vertical landing (STOVL) capability, such as the Harrier, are limited to subsonic operation. NASA Lewis is sponsoring studies with three engine companies for assessing the potential of advanced propulsion concepts and technology to achieve viable supersonic STOVL fighter capability. These studies with Pratt & Whitney, General Electric, and Allison are evaluating a wide range of candidate STOVL propulsion concepts such as vectored thrust, remote augmented lift, ejector augmented lift, tandem fan, and lift plus lift/cruise engines. During their unique vertical landing these propulsion concepts change their mode of operation to deflect engine airflow downward, and some concepts turn on separate lift engines or augment propulsive

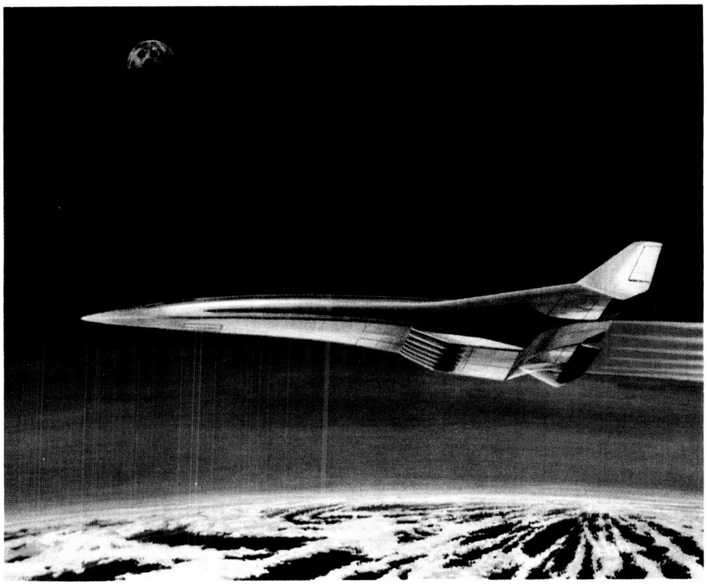


Supersonic STOVL aircraft (artist's concept)

lift through remote heat addition or ejector action.

Each engine company has been teamed with an airframe manufacturer to study and assess airframe and engine integration issues that will define the technology programs needed to fly a supersonic STOVL airplane in the late 1990's. Preliminary results indicate that viable supersonic single-engine fighter aircraft are possible with full military mission capability, including the added advantage of very short takeoff and vertical landing. These studies support several current technology programs that focus on elements common to the candidate propulsion concepts. In addition, plans are being formulated to address concept-specific technology issues.

Lewis contact: Charles L. Zola, (216) 433–5648
Headquarters program office: OAST



National Aerospace Plane (artist's concept)

National Aerospace Plane Propulsion

NASA Lewis is conducting research and development related to the propulsion system for the National Aerospace Plane (NASP) X–30 vehicle. This work includes inlets, nozzles, combustion, controls, hydrogen propellants, materials, and structures. Lewis has conducted tests of inlet concepts and hydrogen-fueled engine systems to demonstrate advanced propulsion concepts. Balancing the high-speed and low-speed operating characteristics of the components and the propulsion system has been a major focus of these efforts. Wind tunnel testing of an inlet for a Mach 5 engine system will start late in 1988. This test will be aimed at controlling performance with boundary layer bleed and at obtaining data for verifying analytical flow codes.

Analytical codes are being developed to predict the high-speed internal flows in the engine components and to predict the characteristics of metal-matrix composite structures. Hydrogen propellant work is proceeding under Lewis' direction to develop slush hydrogen, a mixture of approximately 50 percent solid suspended within liquid hydrogen, as a usable fuel. Other propellant work is focused on converting parahydrogen to the ortho state by using advanced catalysts in order to provide a 20 percent increase in heat sink capacity for structural cooling.

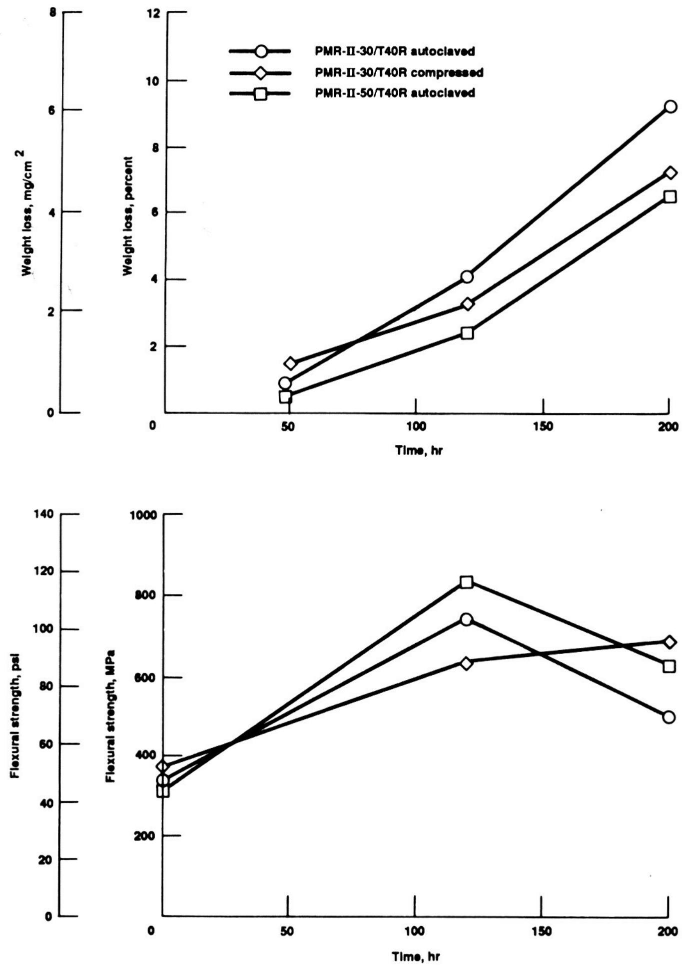
Lewis contact: John E. Rohde, (216) 433–3949
Headquarters program office: OAST

Materials

Autoclave Process for PMR–II 700 °F Matrix Resin Composites

PMR–15 polyimides are being used in a number of composite engine components presently in production or soon to be introduced into production. Although PMR–15 has resulted in significant cost and weight benefits, its applications have been limited to those sections of the engines operating in the 500 to 600 °F range. If the performance requirements for new advanced engine designs, which dictate higher thrust-to-weight ratios, are to be met, composites must be used in the hotter sections of the engines.

Since PMR–15 does not meet the requirements for use in the hotter engine sections, NASA Lewis recently introduced the more thermally stable, high-molecular-weight (HMW) PMR–II series of resins. Graphite-reinforced PMR–II composites tested after exposure to the severe oxidative environment of 60-psi air at 700 °F exhibited excellent retention of properties for more than 200 hr of continuous exposure. The oxidative stability of PMR–II resins is attributed to both the use of more stable reactants and the high-molecular-weight formulations used to prepare the resins. A disadvantage of PMR–II formulations is that they severely retard resin flow during processing, and therefore high pressures (1000 psi or greater) are required to fabricate quality laminates. Since most large composite structures require autoclave fabrication at pressures of 200 psi or less, the intractability of PMR–II resins severely limits their application.



Weight loss and flexural strength of two graphite/PMR–II resin laminates after exposure to 4 atm of air at 700 °F

A recent study aimed at improving the processability of HMW PMR–II resin materials resulted in the development of a new autoclave curing process. The process requires the use of high vacuum, for consolidating the material

before it advances to the intractable state, and pressures of 200 psi or less. The oxidative weight loss and flexural strength retention of compression-molded and autoclave-molded laminates prepared from the PMR–II resins and T40R graphite fiber were compared after exposure to 4 atm of air at 700 °F. The autoclaved laminates compared favorably with the laminate that was compression molded at 2000 psi.

Bibliography

Vannucci, R.D.; and Cifani, D.: 700 °F Properties of Autoclave Cured PMR–II Composites. Proceedings of 20th SAMPE International Technical Conference, Minneapolis, MN, Sept. 1988.

Lewis contact: Raymond D. Vannucci, (216) 433–3202
Headquarters program office: OAST

Thermomechanical Properties of Chemical-Vapor-Deposited Silicon Carbide Fibers

For advanced hypersonic engine applications, where structural components must be strong, stiff, and capable of withstanding high temperatures in oxidative environments, intermetallic and ceramic composites reinforced by continuous, high-performance silicon carbide (SiC) fibers are prime material candidates. Because of their high as-produced strength and modulus, major interest is being directed toward SiC fibers produced by the chemical vapor deposition (CVD) of polycrystalline SiC onto a nonreactive carbon substrate. A study has recently been conducted at NASA Lewis to determine the thermomechanical properties of commercial 142-μm-diameter CVD SiC fibers (Textron SCS–6) and to assess their potential for providing structurally and environmentally reliable ceramic matrix composites.

Measurements to temperatures as high as 1600 °C were made for such fiber properties as axial thermal expansion, tensile and flexural modulus, tensile creep, flexural damping, tensile strength at temperature and after high-temperature exposure, and transverse thermal conductivity. Test environments included vacuum, argon, and oxygen. These data revealed behavior expected of polycrystalline β–SiC, but with some significant deviations that can apparently be attributed to the carbon substrate and to free silicon within the SiC grain boundaries. The particularly detrimental effect of the silicon was evident in the time-dependent deformation and fracture properties above 600 °C. We concluded that current CVD SiC fibers are not adequate for reinforcement of high-temperature ceramic composites but that future CVD fibers with smaller diameters and stoichiometric SiC deposits should be suitable.

Bibliography

DiCarlo, J.A.: High Temperature Properties of CVD SiC Fibers. Presented at the International Conference on Whisker- and Fiber-Toughened Ceramics, American Society for Metals, Metals Park, OH, 1988. To be published.

Lewis contact: Dr. James A. DiCarlo, (216) 433–5514
Headquarters program office: OAST

Thermodynamic Analysis of Chemical Compatibility of Several Reinforcement Materials With Aluminide Matrices

Fiber-reinforced intermetallic matrix composites are being considered as potential high-temperature materials. One of the essential requirements in selecting a suitable fiber reinforcement material is its chemical compatibility with the matrix. Detailed experimental studies on fiber-matrix interaction can be time consuming if several potential reinforcement materials need to be considered. On the other hand, predicting the chemical stability of the reinforcement material in a given matrix by thermodynamic modeling can narrow the choices for reinforcement materials. The most promising systems can then be taken for detailed experimental analysis.

The chemical compatibility of several high-melting-point inorganic compounds (carbides, borides, oxides, nitrides, silicides, and beryllides) with NiAl and FeAl matrices having 40 to 50 at. % aluminum has been analyzed thermodynamically. A few chemically compatible reinforcement materials were identified. The materials compatible with NiAl at 1373 to 1573 K are

Al_2O_3	HfN	TiB_2
AlN	HfO_2	TiC
BeO	La_2O_3	TiN
$CaZrO_3$	Mo_3Si	Y_2O_3
Gd_2O_3	Mo_5Si	$Y_2O_3 \cdot 2ZrO_2$
HfB_2	ScB_2	ZrN
HfC	Sc_2O_3	ZrO_2

Those compatible with FeAl at 1173 to 1273 K are

Al_2O_3	HfN	TiC
AlN	La_2O_3	Ti_5Si_3
BeO	ScB_2	Y_2O_3
Gd_2O_3	Sc_2O_3	ZrB_2
HfB_2	TiB_2	ZrC
HfC		

Thermodynamic calculations are continuing to identify chemically compatible reinforcement materials for Ti_3Al + Nb and $NbAl_3$ matrices. Thermodynamic modeling is also being employed to identify chemically compatible coating compositions for currently available ceramic fibers.

Lewis contact: Ajay K. Misra, (216) 433–5497
Headquarters program office: OAST

Oxidation Resistance of β–NiAl + Zr

Materials used in aeropropulsion applications must generally be capable of performing in a cyclic, oxidizing environment. Because it is a highly oxidation-resistant material, β–nickel aluminide has been widely used as a protective coating for turbine alloys. It has recently been proposed for use as a matrix material in a fiber-reinforced composite. A fundamental understanding of oxidation resistance under cyclic test conditions is essential in assessing the potential for using this fiber-reinforced composite in engine components.

The cyclic oxidation resistance of NiAl + Zr was addressed in a recent study. Excellent oxidation resistance was retained after 3000 1-hr cycles at 1200 °C. A detailed model of the oxidation and spalling process was used to describe these oxidation data accurately. The fractional amount of oxide spalled per cycle can be defined by a spall constant Q_o and the following equation:

$$W_s = Q_o(W_r')^2$$

where

W_s weight of oxide spalled
Q_o spall constant
W_r' weight of retained oxide prior to spalling

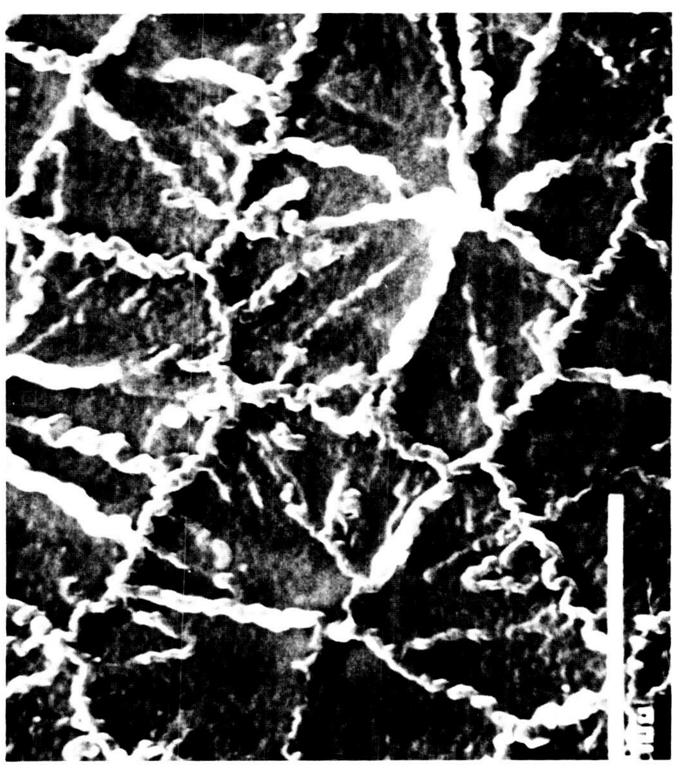
For NiAl + Zr the following growth and spalling constants (k_p and Q_o) have been determined as a function of temperature:

Temperature, °C	Growth constant, k_p, mg^2/cm^4 hr	Spall constant, Q_o
1100	0.0020	1.5×10^{-5}
1150	.0066	1.3
1200	.0142	7.4

This model projects metal consumption at 1200 °C and 10,000 hr to be 25 mg/cm^2 of aluminum. This is equivalent to consumption of all the aluminum in 43 μm of NiAl (i.e., only about 1.7 mil). On the other hand, NiAl without Zr spalls readily to bare metal, exhibits a drastic weight loss, and has spalling factors 100 to 10,000 times greater than those of NiAl + Zr. This underscores the importance of using oxygen-active dopants to maintain Al_2O_3 scale adhesion.

In an associated study the evolution of Al_2O_3 scales on NiAl + Zr was examined as a function of temperature. Isothermal growth rates followed two curves in a standard Arrhenius plot of k_p vs $1/T$. At about 1000 °C the growth rates dropped discontinuously to the power branch. X-ray diffraction studies revealed that the drop in scale kinetics occurred simultaneously with a transformation from θ–Al_2O_3 to α–Al_2O_3. As θ–Al_2O_3 is a less closely packed structure, its fast kinetics are believed to result from faster lattice diffusion. This transformation was also found to be the cause of a peculiar scale microstructure. That is, as nuclei of α–Al_2O_3 grew laterally, they produced a network of ridges corresponding to the last scale region that changed to slower kinetics. The θ–α volume contraction also produced radial cracks in the scale that were the sites of secondary ridge formation. These studies allowed us to understand the mechanisms of NiAl oxidation and the time and temperature limitations of this material.

Lewis contacts: James L. Smialek, (216) 433–5500; Charles A. Barrett, (216) 433–3163
Headquarters program office: OAST



Development of oxide ridge network in mature α–Al_2O_3 scales after 100 hr at 1100 °C

Structural Mechanics

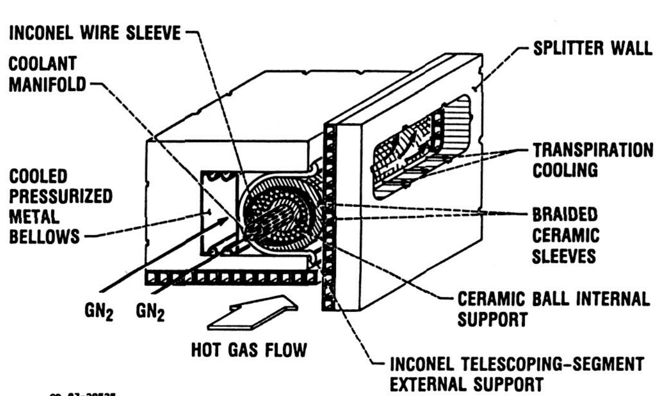
Dynamic, High-Temperature Flexible Seal

Essential to the successful operation of high-performance, hypersonic engines is the development of advanced high-temperature flexible seals for the gaps between movable engine panels and their adjacent stationary engine sidewalls. Gaps caused by pressure and thermal loads on the relatively compliant engine sidewalls can be as much as 0.25 in. (6.4 mm). Very compliant "serpentine" seals are required to conform to this distortion. Such a seal is expected to prevent engine-flow-path gas as hot as 1200 to 5000 °F and pressurized to 100 psi from leaking past the engine panels to back engine cavities, where it could cause loss of an engine or an entire aircraft.

The new seal consists of multiple plies of braided ceramic sleeves filled with small ceramic balls. The innermost braided sleeve is supported by a high-temperature-wire-mesh sleeve that provides both springback and preload capabilities. The ceramic balls reduce the effect of the relatively high porosity of the braided ceramic sleeves by acting as a labyrinth flow path for the gases and thereby greatly increasing the pressure gradient that the seal can sustain. This arrangement provides a highly flexible seal structure that can operate continuously at up to 2000 °F without coolant. The seal can also operate at the maximum engine gas temperatures if transpiration cooling is used.

Designed as the first-stage seal of a multistage seal system, this concept combines initial sealing and thermal barrier capabilities in a simple, flexible package. This dynamic, high-temperature, flexible seal can be employed in hypersonic engines, two-dimensional convergent/divergent and vectorized-thrust exhaust nozzles, reentry vehicle airframes, rocket motor casings, high-temperature furnaces, and any application requiring nonasbestos high-temperature gaskets.

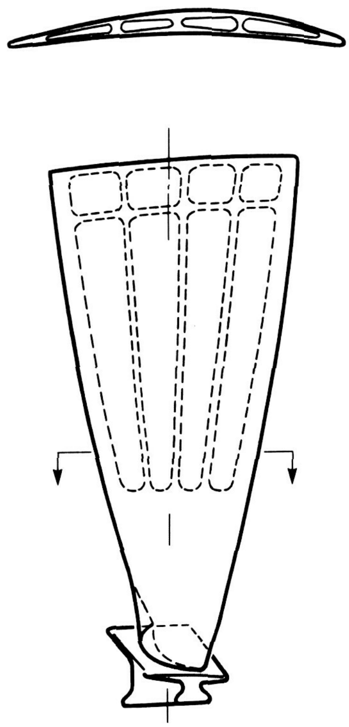
Lewis contact: Bruce M. Steinetz, (216) 433–3302
Headquarters program office: OAST



Dynamic, high-temperature flexible seal

Aerostructural Tailoring of Engine Blades

Fan and compressor blades are designed to provide aerodynamic performance and structural durability through aerodynamic and structural design iterations. These design iterations require that specific design criteria, determined through empirical correlations, must be satisfied. The aerodynamics engineer seeks a blade that has maximum performance, regardless of the airfoil durability. The structural designer, on the other hand, must design a blade that is structurally durable with little or no penalty in performance. To design a structurally durable blade, the structural designer conducts vibration, steady-state stress, and ingestion analyses of proposed designs, allows design modification for reanalysis, compares analysis results with design criteria, and



Hollow fan blade

AERO/STAEBL performs complex multidiscipline design optimization of engine blades

assembles the input required to perform flutter and flight cycle life analyses. The blade designer must often use personal experience and intuition to establish which path to follow in improving a design and to decide when a design is adequate.

Once the structural engineer has found a blade that satisfies the structural durability requirements (constraints), it must be sent back to the aerodynamicist for efficiency evaluation. The aerodynamicist will often make slight changes to the blade to try to maintain flow area, efficiency, and thrust. The blade must again be analyzed by the structural engineer, perturbed, and passed back to the aerodynamicist. A blade may go through several intergroup iterations, lasting several months.

Thus current turbine engine blade design procedures are partly engineering and partly art. The quality of a design often depends on the judgment and experience of the engineering team that performed the design task. The penalties for these less-than-optimum designs are increased engine weight and cost, decreased efficiency, and needlessly long development cycles. Correcting a problem is always more expensive than conducting the design correctly initially, when constraints are less rigid. A design fault is usually corrected at the expense of engine cost or weight, and overall engine performance is generally degraded.

An aerodynamic and structural optimization computer software system, Aerostructural Tailoring of Engine Blades (AERO/STAEBL), has been developed by Pratt & Whitney under a NASA Lewis contract. This code augments the previous STAEBL code to include the aerodynamic analysis. The capabilities of AERO/STAEBL include (1) approximate analyses, (2) numerical optimization strategy, and (3) refined analyses. The approximate analyses are for aerodynamic efficiency, steady-state stress, low cyclic fatigue, vibratory fatigue, flutter, and foreign object damage. The optimization strategy is a function of the aircraft direct operating cost plus interest. AERO/STAEBL was used to structurally tailor a fan blade having two distinctly different configurations of complex internal geometry: (1) a hollow titanium blade with internal reinforcing ribs and composite inlays, and (2) a superhybrid composite blade combination of boron/aluminum and graphite/epoxy composites with a titanium surface and mid-plane plies. AERO/STAEBL obtained optimum designs that met all the aerodynamic and structural design requirements with substantial reductions in weight and direct operating cost plus interest.

Bibliography

Brown, K.W.: Aero/Structural Tailoring of Engine Blades (AERO/STAEBL). (PWA-5774-82, Pratt & Whitney Aircraft; NASA Contract NAS3-22525) NASA CR-180805, 1988.

Chamis, C.C.: Composite Mechanics for Engine Structures. NASA TM-100176, 1987.

Chamis, C.C.; and Ginty, C.A.: Fiber Composite Structural Durability and Damage Tolerance: Simplified Predictive Methods. NASA TM-100179, 1987.

Chamis, C.C.: Design Procedures for Fiber Composite Box Beams. NASA TM-100296, 1988.

Chamis, C.C: Mechanics of Composite Materials: Past Present, and Future. NASA TM-100793, 1988.

Lewis contact: Dr. Christos C. Chamis, (216) 433-3252
Headquarters program office: OAST

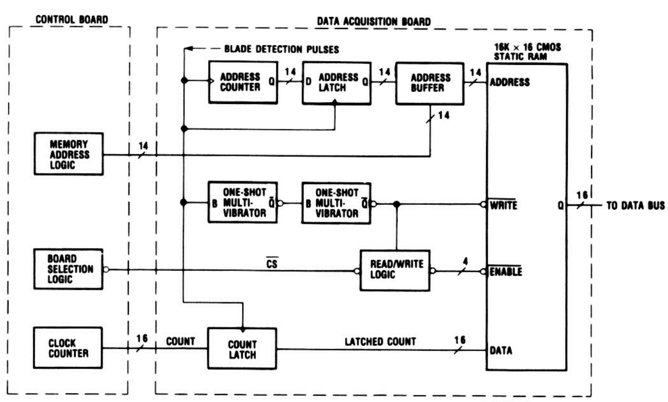
Data Acquisition System for Rotor Vibrations

A new optical data acquisition system designed at NASA Lewis measures the vibrations of rotor blades. The system records raw data—a set of blade arrival times—in memory and processes the data after the run. This approach yields a simple and inexpensive system with the least possible hardware. The system replaces a more complex system in which a set of fixed optical probes sensed blade passages, a microcomputer received and processed data from the probes, and a control computer sorted the data into usable form. The older system was costly and difficult to maintain and repair. The new system requires fewer circuit boards. Because it is simpler, it is more reliable; and self-testing circuitry can be eliminated as well. The new system nevertheless retains the important performance characteristics. Its maximum allowable deflection, deflection resolution, maximum (unaliased) frequency, and frequency resolution are equal to or better than those of the older system.

In the new system 16 probes are equally spaced around the circumference of the chamber that contains the rotor. Each probe contains three high-resolution optical reflective sensors and associated electronics. The sensors are focused light-emitting diodes (LED's) and matched photodetectors in unitary packages. A visible light beam from each LED is focused at the blade tip path. As a blade passes by the probe at high speed, the event is detected, converted to a signal compatible with logic circuitry, and sent to one of four data acquisition boards. The probes variously measure the start of a revolution and the positions of the leading edge of the blade tip, the tip midchord, and the tip trailing edge at four locations.

Because four optical probes share a single memory, the address size of the memory on each board had to be increased from 4K to 16K in order to obtain the same number of data points per probe as in the original system. However, the total address sizes of the memories for all the probes remain unchanged. One penalty for the simplicity of the new system is that the size of a memory word must increase. The eight-bit memory-word size of the original system is now adequate only when a high-speed wraparound clock counter is used to measure time. Although counter wraparound can be handled by software, the counter must not wrap around before the next blade arrives if it is to produce meaningful, unscrambled timing records. A 16-bit memory-word size satisfies this racing limitation at clock speeds as high as 20 MHz for the worst case of a two-blade rotor at 3000 rpm.

Additional measures were taken to simplify the data acquisition boards and to reduce the number of components. The time interval incorporated into the equipment design to correct for missing or extraneous blade signals was eliminated and replaced with an equivalent interval generated by a controlling computer program. This offers the further advantage of easy modification of the interval as needed. The master clock and the wraparound clock counter are located on a separate



Data acquisition system for rotor vibration

control board, which also has control circuits for connection to an external computer. During the acquisition, storage, and retrieval phases of a data collection run, the control circuits enable or disable control lines to the data acquisition boards, as called upon by software.

Bibliography

Posta, S.J.; and Brown, G.V.: A Low-Cost Optical Data Acquisition System for Vibration Measurement. NASA TM–88907, 1986.

Lewis contacts: Stephen J. Posta, (216) 433–6045; Dr. Gerald V. Brown, (216) 433–6047

Headquarters program office: OAST

Predicting Propfan Flutter

A theoretical model and an associated computer program were developed at NASA Lewis for predicting subsonic bending torsion cascade flutter in propfans. The predictions of the model were compared with the results of experiments. Additional parametric studies illustrated how the flutter speed was affected by steady aeroelastic deformations, the blade setting angle, the rotational speed, the structural damping, and the number of vibrational modes.

The nonlinear equations of aeroelastic motion were written for a finite-element model of a blade. They are valid for calculating the speeds of stalled and unstalled flutter, forced response, aeroelastic performance, steady-state deflections, and the frequencies and shapes of vibrational modes. Because it was computationally inefficient to integrate them directly in the time domain, the nonlinear equations were treated by a standard perturbation approach, yielding a nonlinear set of equations for the steady-state configuration and a linear set for the perturbations about the steady state. The steady-state deflections and effective total stiffnesses obtained from the solution of the nonlinear equations were used to find the normal vibrational modes. The general vibratory motion was calculated as a superposition of normal modes.

The calculations were performed by using parts of the ASTROP computer code: ASTROP2, based on two-dimensional, subsonic, unsteady aerodynamics; and ASTROP3, based on three-dimensional, subsonic, steady and unsteady aerodynamics. In ASTROP2 the blade is divided into discrete aerodynamic strips, within each of which its properties are constant. Each swept strip undergoes plunging and pitching motions. In ASTROP3 the blade is discretized with nine radial times eight chordwise panels for calculating aerodynamic loads.

In general, the flutter speeds and interblade phase angles predicted by the computer code agreed well with experimental values. However, the flutter frequencies predicted by a three-dimensional, unsteady aerodynamical theory were slightly higher than measured ones, and those predicted by two-dimensional theory were less accurate than were those predicted by three-dimensional theory. Other findings include the following:

(1) Steady-state aerodynamics sometimes exerted significant influence on the steady-state configurations, vibrational modes, and flutter.

(2) Both theory and experiment showed that stability decreased

with an increase in the number of blades, apparently owing to effects of cascades.

(3) Both theory and experiment showed that an increase in the blade setting angle is destabilizing.

For the rotor considered, the flutter mode was dominated by the first two normal vibrational modes of the blades, and there was strong coupling between these modes. Both theory and experiment showed that under certain conditions two interblade-phase-angle modes with slightly different frequencies may be present during flutter. The flutter interblade phase angle is a function of the blade setting angle and the number of blades.

Bibliography

Kaza, K.R.V., et al.: Analytical Flutter Investigation of a Composite Propfan Model. AIAA Paper 87-0738, Apr. 1987. (NASA TM-88944.)

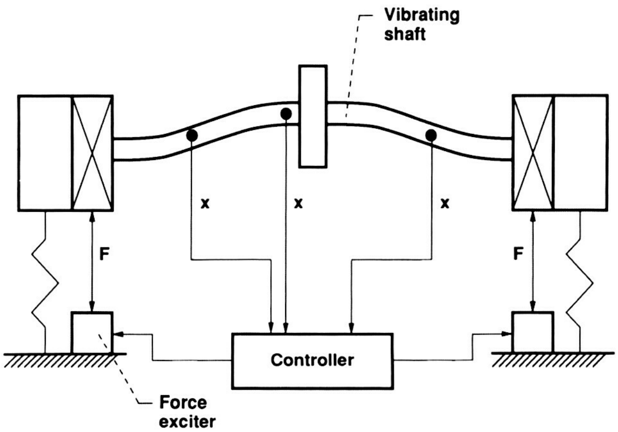
Lewis contact: George L. Stefko, (216) 433-3920

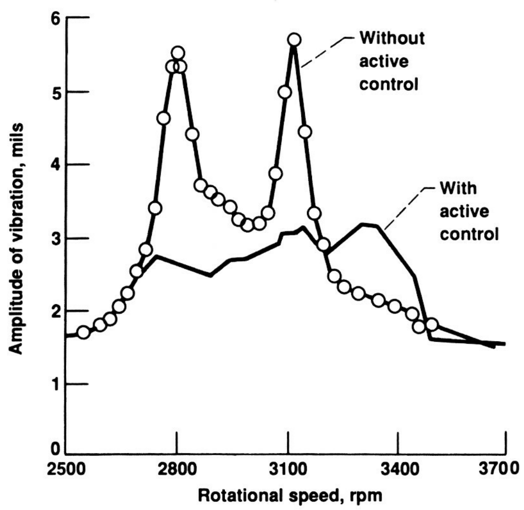
Headquarters program office: OAST

Active Suppression of Rotor Vibrations

In active rotor control the vibrations of flexibly supported rotors are suppressed by an electronic feedback control system. The feedback control system senses the vibration level of a rotor system and provides damping to maintain that level within acceptable limits. This enables a rotor to operate through and above its critical speeds, extends bearing life, reduces the size and weight of rotating shafts, and generally enables rotors to operate more smoothly.

The significant features of the NASA Lewis active rotor-control system are the electronic controller and the force exciters.



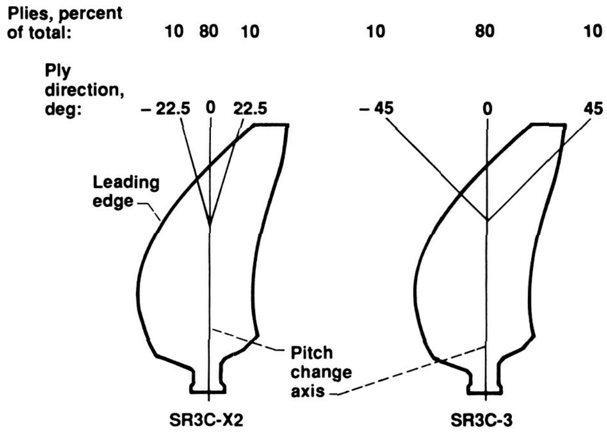


Active rotor control system

The vibration velocity x is sensed, and the sensor output is sent to the electronic controller, which processes the velocity signal and commands the force exciters to provide the desired level of damping force F to the rotor support.

The electronic controller is programmed by entering feedback coefficients to provide any desired percentage of critical damping. The feedback coefficients are calculated by a computer program and are based on a modal analysis of the vibrating rotor system. Preliminary experiments on the active rotor-control system have demonstrated that a high degree of damping is achievable.

Lewis contact: Eliseo DiRusso, (216) 433-6027
Headquarters program office: OAST



Blade ply directions of composite blades used for mistuned wind tunnel model

Effect of Mistuning on Propfan Flutter

The effects of mistuning on propfan subsonic flutter have been analytically and experimentally investigated. The analytical model is based on the normal modes of a rotating composite blade and on three-dimensional unsteady lifting-surface (cascade) aerodynamic theory developed for this analysis. A mistuned wind tunnel model was constructed by alternately mounting two sets of composite blades (SR3C–X2 and SR3C–3). These blades were molded from graphite-ply, epoxy-matrix laminates with different ply directions. The analytical model was validated for selected cases by comparing predicted and measured flutter characteristics of the mistuned wind tunnel rotor (SR3C–X2 and SR3C–3).

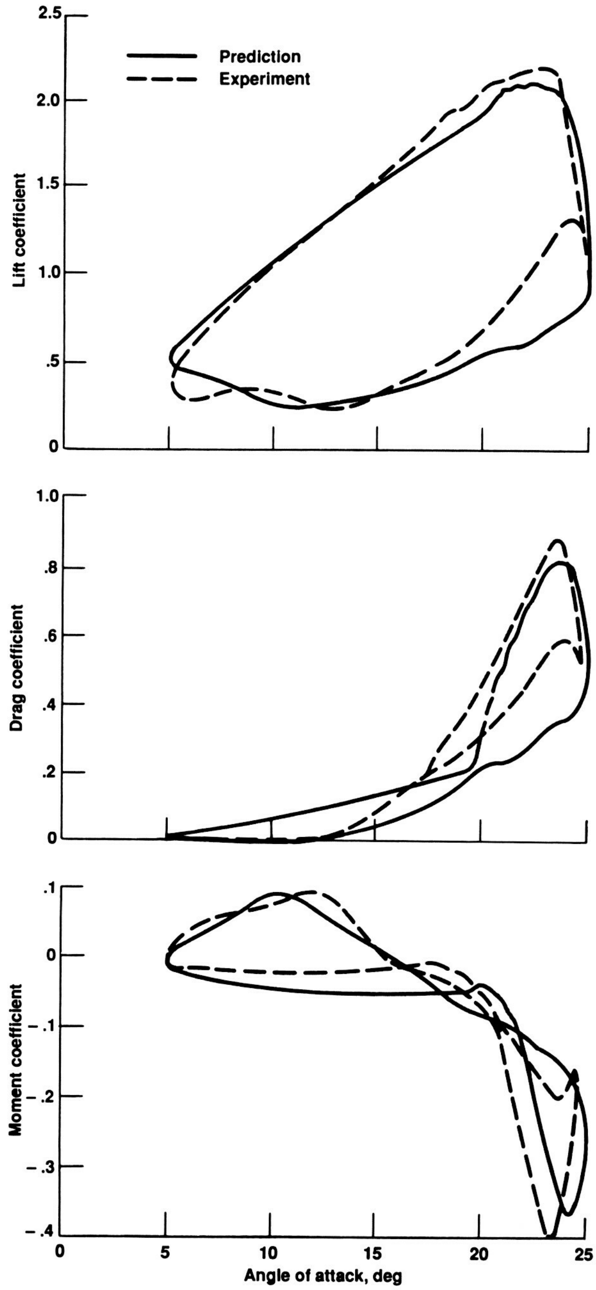
After the code had been validated, additional parametric studies were conducted. The results showed that the combined mode shape, frequency, and aerodynamic mistuning can have either a beneficial effect or an adverse effect on blade damping, depending on the Mach number range. The results also indicated that alternate frequency mistuning does not have enough potential for it to be used as a passive flutter control in propfans similar to the one tested in the present investigation. A laminated composite propfan blade can be tailored to optimize its flutter speed by properly selecting the ply angles.

Lewis contact: Oral Mehmed, (216) 433-6036
Headquarters program office: OAST

Predicting Airfoil Flutter

A procedure was developed for predicting the one- or two-degree-of-freedom flutter characteristics of arbitrary airfoils at large angles of attack, including separated flow. The fluid model is based on two-dimensional, unsteady, compressible Navier-Stokes equations in a body-fitted coordinate system. The solid-fluid equations are simultaneously integrated in time. This is a first step in modeling a complex separated-flow phenomenon over oscillating airfoils, propfans, and turbofan rotors by exploiting the capabilities of supercomputers.

After the analytical model was validated for classical flutter solutions, two sets of stall flutter calculations were performed for flow over the NACA–0012 airfoil at a Mach number of 0.3 and a Reynolds number of 9 million. In the first set the airfoil was perturbed from a steady angle of attack of 15°, and in the second set it was perturbed from 23.82° (not shown here). The dimensionless speed was varied from 4 to 8. In both sets the airfoil was stable when the speed was 4 and was unstable when the speed was 8. For assurance that flutter response was not a classical one, the calculations were repeated at lower angles of attack (between 8° and 10°), but no flutter was found.



Comparison of theoretical and experimental lift, drag, and moment hysteresis loops for unsteady loads on NACA–0012 airfoil

Lewis contact: George L. Stefko, (216) 433–3920
Headquarters program office: OAST

Active Control of Transient Rotor Vibrations

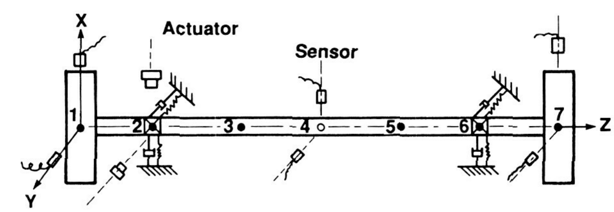
Rotating machinery may experience dangerously high dynamic loading because of the sudden mass unbalance associated with blade loss. Research has been conducted at NASA Lewis to investigate the application of active vibration control methods to suppress rotor vibrations caused by sudden mass unbalance.

A computer model was formed to simulate the NASA rotordynamics rig subjected to sudden unbalance, with and without control. The simulation model included a form of optimal control in modal space with output feedback, pole placement with output feedback, nonlinear on-off control dependent on the sign of the velocity, and nonlinear on-off control dependent on shaft position. The effectiveness of each algorithm was examined in terms of vibration reduction and required actuator force levels. Simulations were made at both 5730 and 12,500 rpm.

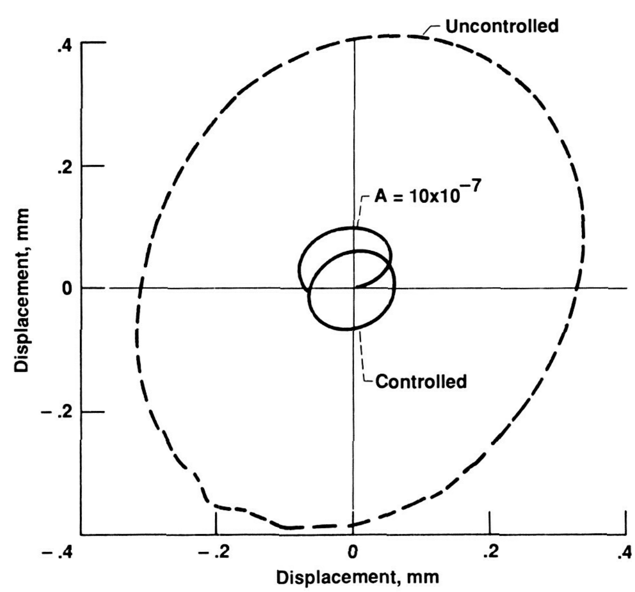
Optimal control, pole placement, and on-off velocity-dependent control can significantly suppress transient vibrations caused by sudden unbalance. On-off position-dependent control was not effective in suppressing vibration. The most effective method appears to be optimal control, based on the computer runs made for this research.

It was found that sensors must be located at all actuator positions (i.e., collocated), in order to avoid instability in the closed-loop system. This is referred to as "spillover" of the higher, uncontrolled modes in a reduced-order model. The best results obtained at 5730 rpm (600 rad/sec) were for optimal control with collocation. The vibrations at the actuator locations were less than 5.5 mils (peak to peak), and the actuator forces were less than 125 N (zero to peak).

Lewis contact: Albert F. Kascak, (216) 433-6024
Headquarters program office: OAST



Schematic diagram for seven-mass rotor model of rotordynamics rig



Seven-mass rotor test results for 5730 rpm and optimal control with collocation

Life Prediction

Fatigue Crack Growth of Single-Crystal Alloy

The ability to accurately predict structural life and reliability depends on understanding the fundamental mechanism of damage initiation and propagation. Recent NASA Lewis studies focused on fatigue crack growth in single-crystal materials used for aircraft turbine blades. This investigation, which was both analytical and experimental, showed that there is a region where the crack growth appears to be independent of the applied stress intensity and has a much higher rate that occurs at a lower threshold stress intensity. Fatigue life estimates for this material (and other materials where this phenomenon can occur) would be very optimistic. A model mechanism based upon barriers to dislocation motion explains the behavior.

A parameter based on resolved shear stresses on slip planes is able to predict the crack paths under two different stress states as well as the crack driving force. This parameter links the phenomenon of quantitative computational applied mechanics at the structural (i.e., stresses and strains) scale to the material science at the microstructural slip plane scale.

These results have relevance beyond the single-crystal material. Much of the fatigue life of conventional materials is used up in forming cracks (i.e., on "short" cracks). These cracks are short in comparison with the single-crystal grain size of the conventional material. Thus the behavior of these short cracks should be similar to the long-crack behavior noted in the subject single-crystal material. If so, this research will add greatly to the understanding of material behavior and the accuracy of life prediction methodology.

Bibliography

Telesman, J.; and Ghosn, L.J.: Accelerated Fatigue Crack Growth Behavior of PWA 1480 Single Crystal Alloy and Its Dependence on the Deformation Mode. NASA TM–100943, 1988.

Lewis contact: Jack Telesman, (216) 433–3310
Headquarters program office: OAST

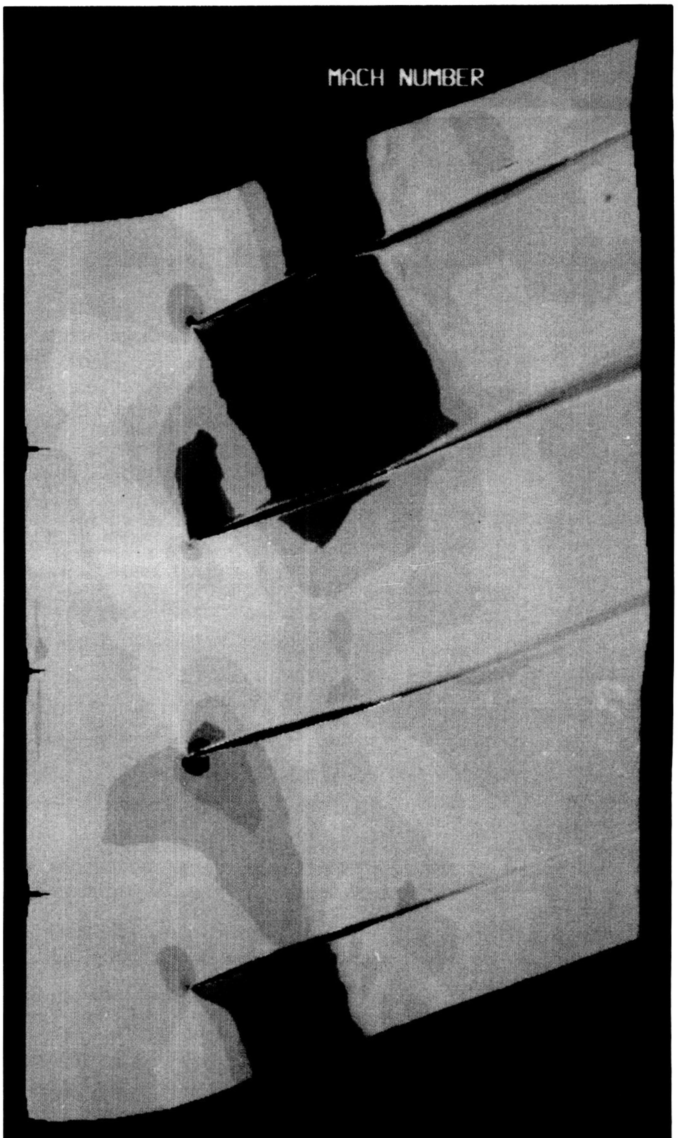
Internal Computational Fluid Mechanics

Computational Analysis of Oscillating Cascades With a Deforming Grid

Analyzing the flow around advanced turboprop airfoil sections requires methods capable of modeling unsteady, transonic flow. As the number of blades increases, the cascade effects become more significant. To date, most of the flow codes that model unsteady, transonic cascades are linearized potential solvers. Although these codes are fast and practical for load predictions, they are not expected to model the true physics of the flow common to classical and stall flutter. Therefore a formulation that models viscous effects and strong shocks is needed to help determine the limits of simplified models.

In an attempt to gain understanding of unsteady, transonic flow through oscillating cascades, NASA Lewis has developed a two-dimensional compressible Navier-Stokes code for such applications. The code introduces a deforming grid technique to capture the blade motion in the cascade. The use of a deforming grid is convenient for treating the outer boundary conditions since the outer boundary can be fixed in space while the inner boundary moves with the blade motion.

The basic development of the code (NS2D3) was completed in April 1987. The code was used for predicting the unsteady loading of a simple NACA–0012 oscillating cascade with zero interblade phase angle. Several improvements have been added to the code, including the capability to model nonzero interblade phase angles and the choice of three turbulence models. The turbulence models use an eddy viscosity and include the zero-equation Baldwin-Lomax model, the one-equation Johnson-King model, and the two-equation K–E model by Gorski. An investigation of nonreflecting, two-dimensional, unsteady boundary conditions is under way to help determine their influence on the first-order pressure distributions used in the unsteady loading predictions. Several flow field predictions have been made with the code for an oscillating cascade of NACA 16-series airfoils (sections typically



Mach number contour predictions for an NACA 16-series oscillating cascade in transonic flow

found on the propfan). The predictions show that the code can model transonic flow and capture the motion of blade-to-blade shocks resulting from intermittent flow choking in individual passages. The predictions are also being validated with data from the NASA Lewis Transonic Oscillating Cascade Facility.

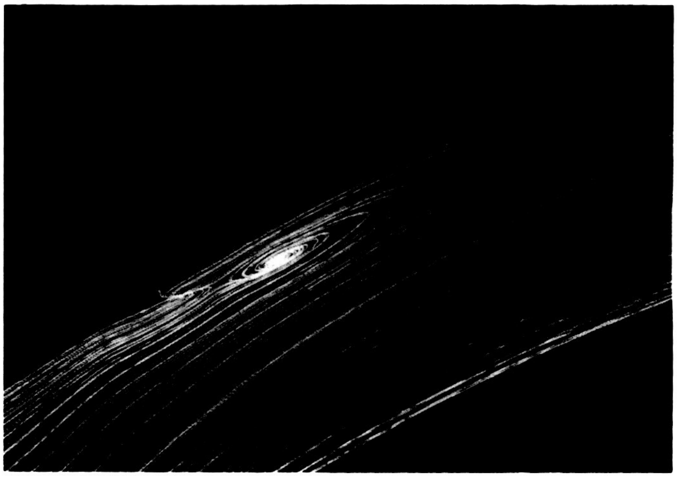
The successful prediction of blade loading in an oscillating cascade has direct applications to aeroelastic analysis of turbomachinery. The development of a compressible Navier-Stokes code should serve as a useful tool for analyzing unsteady transonic flow in highly loaded cascades.

Lewis contact: Dennis L. Huff, (216) 433–3916
Headquarters program office: OAST

Analyzing Flow Separation in Subsonic Diffusing S-Ducts by Using Reduced Navier-Stokes Equations

A reduced form of the Navier-Stokes equations (RNS), originally termed parabolized Navier-Stokes, is considered herein for analyzing three-dimensional subsonic separating flow in diffusing S-ducts. The case considered was the University of Tennessee circular 30°–30° inplane S-bend of area ratio 1.5. The flow in this duct was turbulent with an inlet Mach number of 0.6 and a

Experimental oil flow pattern of flow separation in subsonic S-ducts



Computational oil flow pattern of flow separation in subsonic S-ducts

Reynolds number based on the inlet duct diameter of 1.76 million. In both the experiment and the analysis the flow in the duct separated. This separation was due to the adverse pressure gradient of the area change in combination with the effect of pressure-driven secondary flows. The RNS flow solver marches through regions of confined separation and uses a "flare" approximation to model the separated flow region. The results suggest that a flare approximation can model the effects of separation on the core flow, as indicated by experimental and computational oil flow patterns.

Lewis contact: Bernhard H. Anderson, (216) 433-5822
Headquarters program office: OAST

Hot Gas Ingestion

Through interaction with the ground, aircraft capable of vertical takeoff and landing, such as the Harrier, may ingest hot exhaust gases from the aircraft's vertical lift jets into the engine inlets. This phenomenon, known as hot gas ingestion, can decrease engine performance in two ways: higher inlet temperatures cause a loss in engine thrust, and large variations in inlet temperatures may cause the engine to stall. Proposed supersonic cruise aircraft with vertical landing capability will require higher levels of thrust, leading to a more severe hot gas environment around the aircraft and increasing its susceptibility to hot gas ingestion. Methods to analyze this environment and to evaluate schemes for avoiding or minimizing hot gas ingestion are needed.

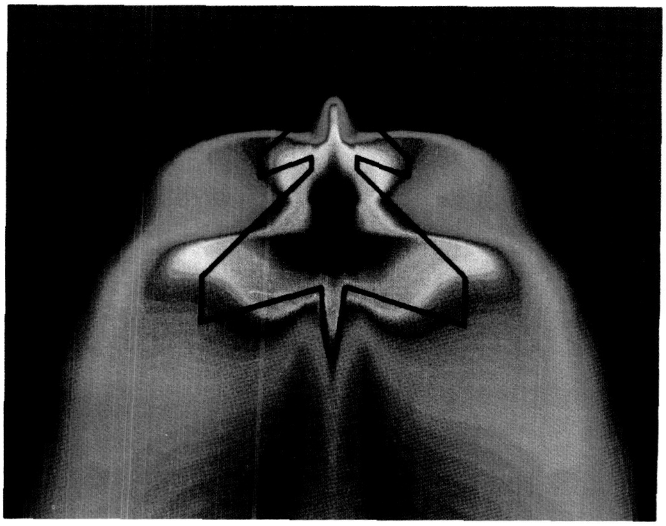
A three-dimensional elliptic internal flow code corresponding to hot gas ingestion model tests in the NASA Lewis 9- by 15-Foot Low-Speed Wind Tunnel was modified to solve for this flow field. Mass flow between the model lift jets and the simulated engine inlet was conserved.

Several cases were run to test the modified flow code. Convergence criteria included monitoring the average inlet temperature. These cases were qualitatively verified by flow visualization studies in the wind tunnel. Calculations were done on the Lewis MVS/XA computer system. The extended architecture allowed the use of more than 120,000 grid points for a full Navier-Stokes code where reverse flow was calculated. Going to the Cray-2 will allow for an even finer mesh and over an order-of-magnitude reduction in processing time. Additional studies are needed to evaluate the accuracy of the modified code.

Bibliography

A Numerical Study of the Hot Gas Environment Around a STOVL Aircraft in Ground Proximity. AIAA Paper 88-2882, July 1988. (NASA TM-100895.)

Lewis contacts: Thomas VanOverbeke, (216) 433-5867; Dr. James D. Holdeman, (216) 433-5846
Headquarters program office: OAST



STOVL ground plane temperature distribution

Multiphase Flows

Future advanced aircraft engines will be required to demonstrate greater fuel efficiency and higher thrust-to-weight ratios than current engines. In order to achieve this level of performance, these advanced engines will have to operate at pressure ratios of 80 and greater. The injection of liquid fuel into a very dense air environment in the combustion chamber will be a key technology for these advanced engines. Computer codes that can accurately simulate the fuel spraying and mixing process will be an important design tool.

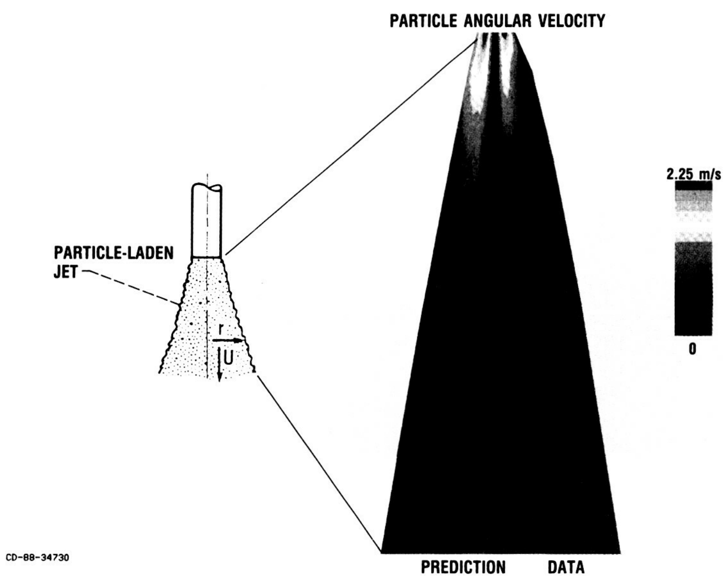
As a step toward the goal of a predictive computational fluid dynamics code for fuel sprays, an in-house study was recently completed at NASA Lewis. The study simulated a liquid fuel spray by using solid glass spheres in a swirling jet. These particle-laden swirling jets were studied in order to obtain experimental data in a two-phase flow that could be used to evaluate current computer models of multiphase flows. Nonintrusive measurements of particle size and velocity as well as gas-phase velocity were obtained. The experimental results were compared with predictions from current two-phase flow models. The best agreement of predictions with the experimental measurements was obtained with a model that accounts for both particle inertia and the effects of gas-phase turbulent fluctuations. Pressure-atomized water sprays are currently being studied as a more accurate approximation to an actual fuel spray. The facility will then be modified in order to study actual fuel sprays with combustion so that computer model capability can be further evaluated and areas for future computer code development identified.

Bibliography

Bulzan, D.L.; Shuen, J.S.; and Faeth, G.M.: Particle-Laden Swirling Free Jets: Measurements and Predictions. AIAA Paper 87–0303, Jan. 1987. (NASA TM–88904.)

Bulzan, D.L.; Shuen, J.S.; and Faeth, G.M.: Particle-Laden Weakly Swirling Free Jets: Measurements and Predictions. AIAA 88–3138, July 1988. (NASA TM–100920.)

Lewis contact: Daniel L. Bulzan, (216) 433–5848
Headquarters program office: OAST



Particle-laden jet velocity contours

Computation of Chemical Reacting Flows

In the past year a new computational fluid dynamics code has been developed at NASA Lewis for the study of mixing and chemical reactions in the flow field of high-speed combustors. The code (RPLUS2D) employs a highly efficient lower-upper (LU) implicit relaxation scheme for solving the two-dimensional Navier-Stokes and species transport equations with real gas properties in a fully coupled manner. In contrast to other implicit schemes, the LU solver requires only scalar inversion for nonreacting flows and diagonal block inversion for problems with finite-rate chemistry, thus saving considerable computer time. For hydrogen air combustion the code employs a 9-species, 18-step finite-rate chemistry model.

The code has been used to simulate the flow field in a model combustor in which high-pressure hydrogen is transversely injected into a supersonic airstream. Computations have also been performed for a model oblique detonation wave engine in which an oblique shock wave in a premixed hydrogen airstream is used to initiate a detonation. Results obtained to date indicate that the code can handle the complex flow field associated with fuel injection, mixing, and chemical reaction in a scramjet combustor. It has also been shown to be very efficient and robust for a variety of complex flows.

A three-dimensional version of the code (RPLUS3D) is currently under development. Results have already been obtained for a nonreacting simulation of an underexpanded jet in supersonic crossflow. Extension to finite-rate, hydrogen-air chemistry is under way.

Bibliography

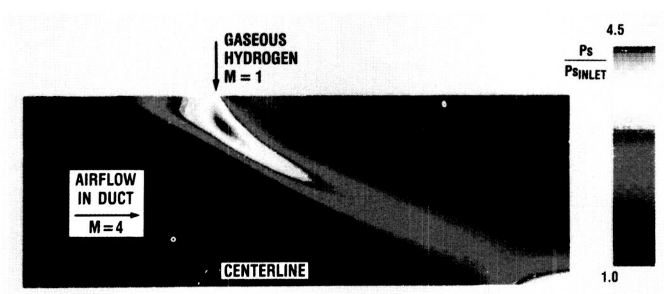
Shuen, J.S.; and Yoon, S.: Numerical Study of Chemical Reacting Flows Using an LU Scheme. AIAA Paper 88–0436, Jan. 1988.

Yu, S.T., et al.: Numerical Simulation of Hypersonic Inlet Flows With Equilibrium or Finite Rate Chemistry. AIAA Paper 88–0273, Jan. 1988.

Yu, S.T.; and Shuen, J.S.: Simulation of Sudden Expansion Ramjet Combustor Flowfields. AIAA Paper 88–3181, July 1988.

Lewis contact: Russell W. Claus, (216) 433–5869

Headquarters program office: NASP



Turbulent reacting flow

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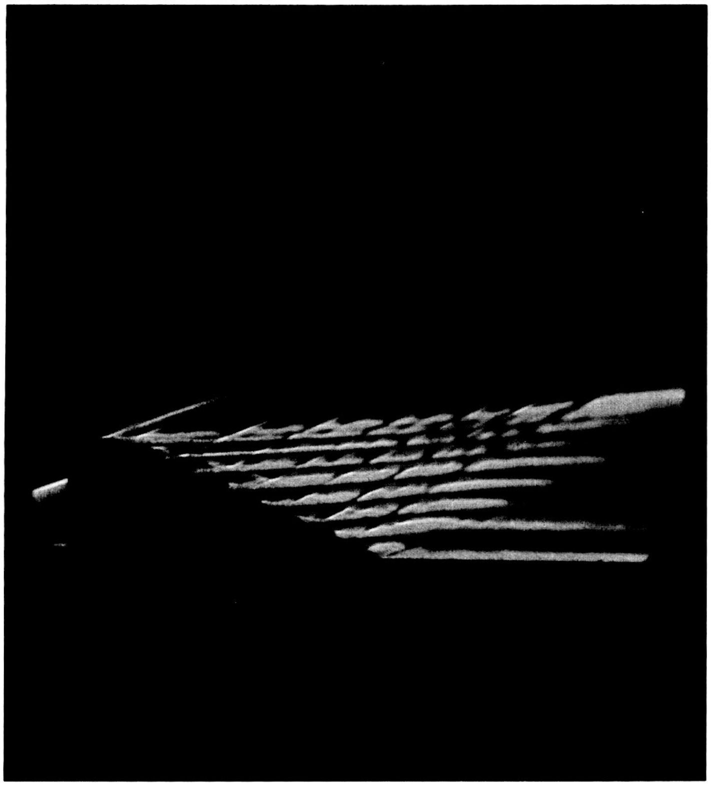


Schlieren photograph of boundary layer simulator experiment at Mach 3.5

Supersonic Boundary Layer Simulation

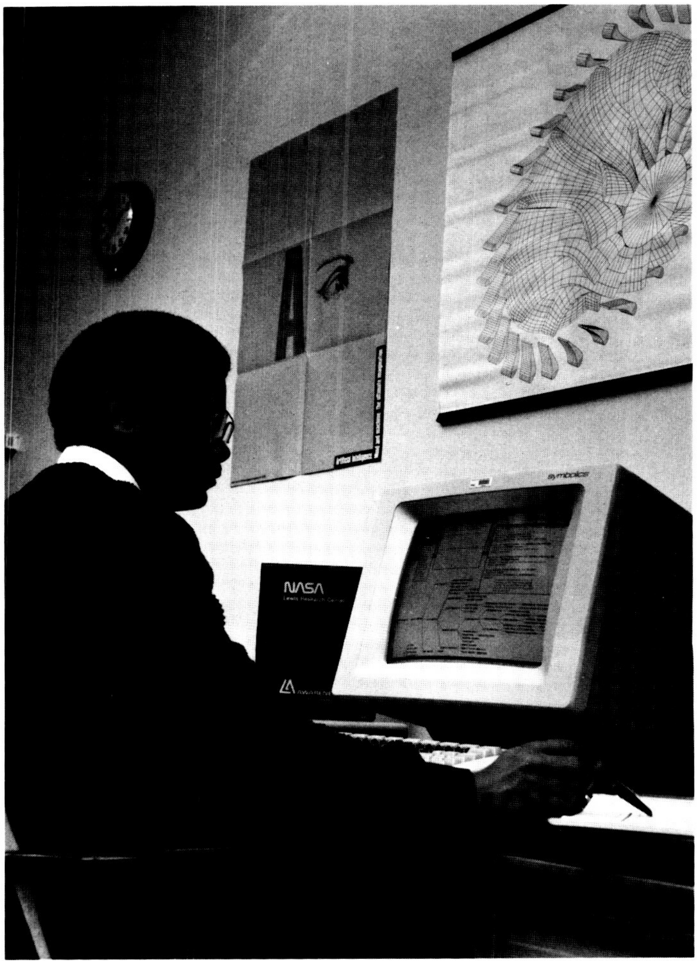
Supersonic and hypersonic aerospace vehicles are configured with a highly integrated airframe and propulsion system. The propulsion system inlet is intimately "wrapped" into the airframe, with a large portion of the aircraft fuselage located directly upstream of the inlet. This type of configuration results in a thick fuselage boundary layer being ingested into the inlet system. The inlet system must be designed to operate properly with this boundary layer and also its interaction with any inlet shock waves. Hence, when inlet experiments are conducted in a wind tunnel for this class of vehicles, this fuselage boundary layer must be properly accounted for. Because a complete inlet and fuselage model would be large, expensive, and more difficult to test, NASA Lewis is developing a technique to simulate a thick fuselage boundary layer in a supersonic flow stream. Using this boundary layer simulator allows the long upstream portion of the fuselage to be eliminated from the wind tunnel test configuration.

The boundary layer simulator consists of a block of honeycomb material with the honeycomb cells aligned parallel to the supersonic flow stream. The length of the cells varies with distance from the wall so that pressure losses can be selectively introduced to develop the desired boundary layer profile. The longest cells are close to the wall and cell length decreases in a prescribed manner away from the wall. By changing the way in which cell length varies with distance from the wall, the downstream boundary layer profile can be tailored to any desired shape.

A series of experiments have been conducted in the 1- by 1-Foot Supersonic Wind Tunnel to assess the performance of the simulator at Mach numbers to 3.5. Results obtained thus far have demonstrated that the simulator provides the desired velocity distribution within the boundary layer, although the distribution of boundary layer turbulence level does not match desired levels. Future experiments will address this turbulence issue as well as extend the technique to higher Mach numbers.

Lewis contact: Dr. Warren R. Hingst, (216) 433–5923
Headquarters program office: OAST

Intelligent Interface to Computational Fluid Dynamics Flow-Solver Codes



PROTAIS being implemented on Symbolics 3600 computer

Computational fluid dynamics (CFD) codes are being developed and used to study the complex fluid behavior internal to aerospace propulsion systems. Many of these codes are written with a specific problem in mind and are very large, very complicated, and not well documented. As a result the codes tend to be difficult for others to understand, modify, and use.

An "intelligent interface" to CFD codes is being developed at NASA Lewis to reduce the amount of knowledge and effort required to run these codes. The interface makes use of artificial intelligence concepts to capture the expertise gained by developers and previous users of the code. The initial version of the interface has been named PROTAIS to denote its application of artificial intelligence to a new Navier-Stokes solver, PROTEUS.

The initial design of the PROTAIS system has been completed. That design provides for two operating modes (one to support expert users and the second to support novice users) and three levels of functional capability. Level 1 provides the basic PROTAIS structure and integrates all of the various code operating procedures into a single high-level interface. At this level the system knowledge bases contain information about the code, defaults, computer protocols, and previous runs. Level 2 adds acquired knowledge about the relationships between PROTEUS variables and their values. Level 3 is where most of the "intelligence" resides. At this level CFD principles will be encoded into PROTAIS to ensure that problem descriptions conform to physical laws.

PROTAIS is being implemented on a Symbolics 3600 computer. PROTAIS software has been written by using a combination of the LISP symbol manipulation language and Knowledge Engineering Environment (KEE) software development tools. The first level of the expert user interface has been programmed and is undergoing testing, with expert users submitting jobs to the Cray X/MP via the Lewis Scientific Ethernet. Significant benefits of using PROTAIS have already been observed: less time is required to set up problems, and being able to visualize and relate results is an added convenience. These benefits are expected to multiply as PROTAIS expands to include more advanced capabilities.

Bibliography

Williams, A.D.: The Development of an Intelligent Interface to a Computational Fluid Dynamics Flow-Solver Code. NASA TM-100908, 1988.

Lewis contact: Anthony D. Williams, (216) 433-3611
Headquarters program office: OAST

Instrumentation and Controls

TCP Design Advisor—An Expert System for Thermocouple Probe Design

The TCP Design Advisor is a prototype expert system designed to be a consultant for the novice and a tool for the expert in designing thermocouple probes for temperature measurement of turbojet engine airflow. For certain classes of probe design problems this expert system can help to determine near optimal probe designs from both performance and geometric viewpoints.

The framework for this expert system is the Knowledge Engineering Environment (KEE) developed by Intellicorp. A full-fledged expert system should have three components: a knowledge/rule base, a user interface, and a builder interface.

The TCP Design Advisor knowledge base contains information on three probe configurations, three thermocouple types, and two classes of probe assembly. The various combinations available will provide solutions for about 80 percent of turbojet engine temperature measurement applications.

This knowledge base also contains engine component data used for setting input defaults, structures for storing user input, structures for storing program output, and the program's rule base. The rule base contains some of the expert's reasoning implemented as if-then rules. The inference engine, part of the KEE software, controls evaluation of these rules. Reasoning not implemented as rules is implemented as a LISP algorithm that augments KEE's inference engine. The LISP algorithm prompts KEE's inference engine to apply groups of rules in a specified order.

The user interface in the TCP Design Advisor has three elements: an input interface, an output interface, and a query interface. The input interface is fairly complete. It uses mouse-sensitive windows as well as the keyboard and checks input for consistency. The output interface for the prototype is comparably primitive and of limited capability. The query interface is KEE's query facility.

The builder interface is an intelligent front end that allow's future users to expand the expert system's capabilities while maintaining the integrity of the knowledge and rule bases.

Several test cases were devised and results from the expert system were compared with those of a probe design expert. The results were in good agreement. This expert system has been used successfully to aid in-house designers.

Lewis contact: Kevin J. Melcher, (216) 433-3743
Headquarters program office: OAST

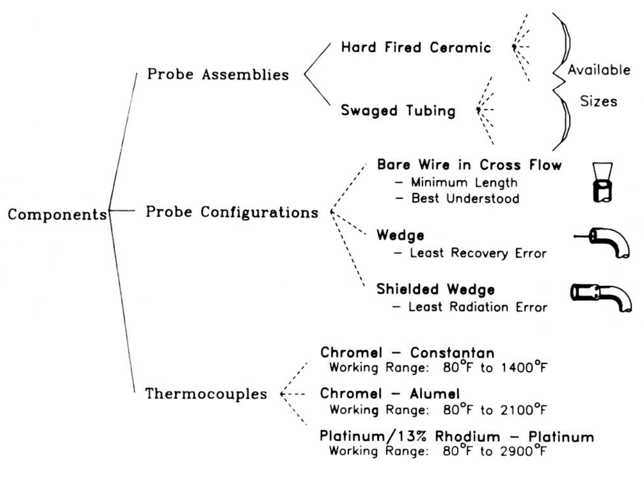


Diagram showing structure of thermocouple knowledge base (simplified)

Propulsion System Components

Oscillating Cascade Experiment

The possibility of flutter in the rotating blade rows of turbomachines and propellers is a continual concern. The ability to predict flutter has not kept pace with the overall advances and new requirements of turbomachinery and turboprop designs. Consequently the development of analyses to address unsteady aerodynamics is of fundamental research interest. Directing this development and evaluating these as well as existing analyses requires data from oscillating cascade experiments. Because these experiments are complex, few results are available at realistic reduced frequencies, particularly in the high subsonic and transonic flow regimes. Therefore NASA Lewis has built the Transonic Oscillating Cascade Facility to provide the needed data.

A major feature of this facility is the high-speed mechanical drive system, which imparts controlled torsional oscillations to the airfoil cascade. The cascade is composed of nine biconvex airfoils with a chord of 7.62 cm, a thickness-to-chord ratio of 0.076, a solidity of 1.3, and a stagger angle of 53° The amplitude of the airfoil motion is 1.2° with a maximum airfoil oscillation frequency of 500 Hz, corresponding to a reduced frequency of 0.462 at a cascade inlet Mach number of 0.80.

The primary data of interest are the complex unsteady surface pressures on the oscillating cascaded airfoils. These data are obtained by flush mounting Kulite transducers along the chord of a reference airfoil. The transducers are placed in milled slots and potted in room-temperature vulcanizing (RTV) material to isolate them from the airfoil strain. All of the unsteady signals are recorded on magnetic tape for postexperiment processing.

A series of experiments have been performed to investigate and quantify the effects of inlet Mach number, reduced-frequency interblade phase angle, and mean flow incidence on the harmonic unsteady fluid dynamics of an oscillating two-dimensional unswept airfoil cascade. The effect of interblade phase angle on the dynamic pressure difference coefficient was investigated for an inlet Mach number of 0.80. For both 90° and −90° interblade phase angles the magnitude data had approximately equal amplitudes near the leading edge, but the amplitudes decreased with increasing chordwise position. However, for a 0° interblade phase angle the magnitude data were lower, with no leading-edge maximum. Also, the phase data increased in a linear manner with increasing chordwise position.

The torsion-mode unsteady aerodynamic moment coefficients were calculated from the unsteady pressure difference data. These together with the corresponding prediction from an unsteady, small-perturbation, subsonic flat-

Airfoil surface unsteady pressure signals for Mach 0.80 and incidence angle of 7°

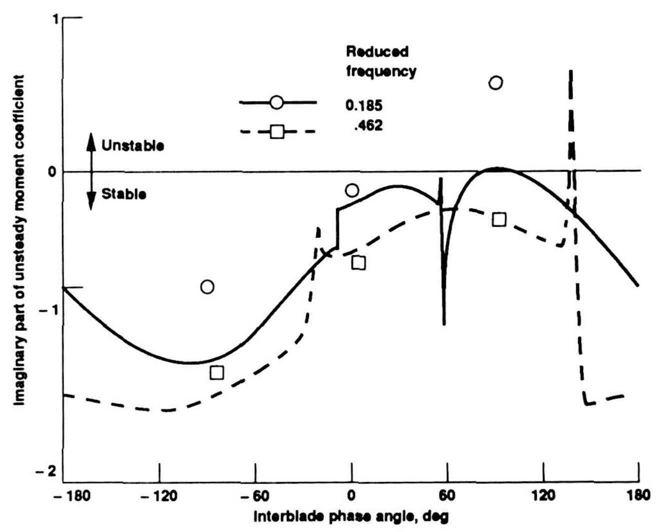


plate cascade analysis were plotted as a function of the interblade phase angle. The data indicated a flutter instability at an interblade phase angle of 90°. The corresponding predictions were consistently lower, indicating a more stable condition (i.e., the predictions were not conservative). However, the predictions did indicate an unstable region near 90°.

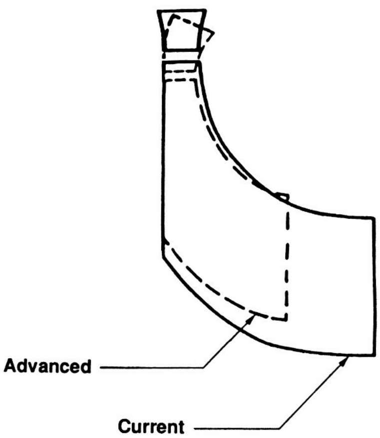
Lewis contact: Daniel Hoyniak, (216) 433-3789
Headquarters program office: OAST

Compact Radial Turbine Rotor

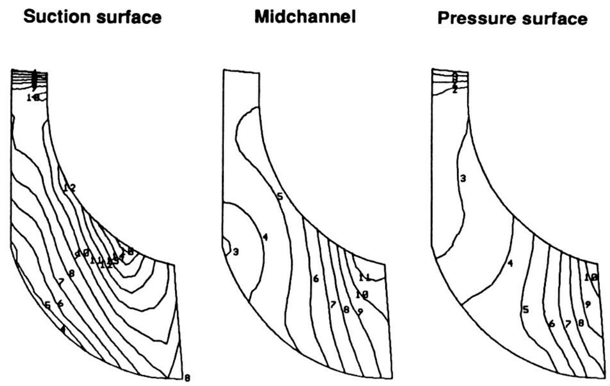
The high efficiency and increased stage work of radial turbines have not been fully exploited in small aircraft propulsion engines, partly because radial turbines are larger and heavier than other turbines. Recently NASA Lewis and Pratt & Whitney Aircraft entered into a joint program to assess the performance potential of advanced, compact radial turbine designs. If successful, a compact radial turbine could fit in the space of two axial stages, develop the same power, and have higher efficiency.

Two compact rotors were analyzed by using state-of-the-art two- and three-dimensional aerodynamic Euler codes. These codes permitted improved blade passage flow control to achieve high aerodynamic loading in the compact designs. The analyses indicated well-controlled flow with no large separation due to the higher aerodynamic loading. Future work will focus on experimentally evaluating the rotor in the Lewis Small Warm Turbine Test Facility and comparing the results with the code predictions as well as on analyzing the designs further with two- and three-dimensional viscous codes.

Lewis contact: Richard J. Roelke, (216) 433-3403
Headquarters program office: OAST



Compact radial turbine



Rotor Mach number contours

Improved Spur Gears for Aircraft Applications

Spur gears are widely used in aircraft to transmit mechanical power between drive shafts with parallel axes. Light weight is essential in aircraft applications, but lightweight gearboxes are prone to deflect when loaded. So in designing an aircraft gearbox, there is a tradeoff between weight and structural rigidity. If emphasis is put on light weight, under flight conditions the gearshafts deflect and become misaligned. When the shafts are misaligned, the load between the mating gears is no longer carried in the ideal way (i.e., uniformly distributed across the face of the gear teeth). Instead, it is concentrated to one edge of the teeth. If this happens, the gears become noisy and soon wear out.

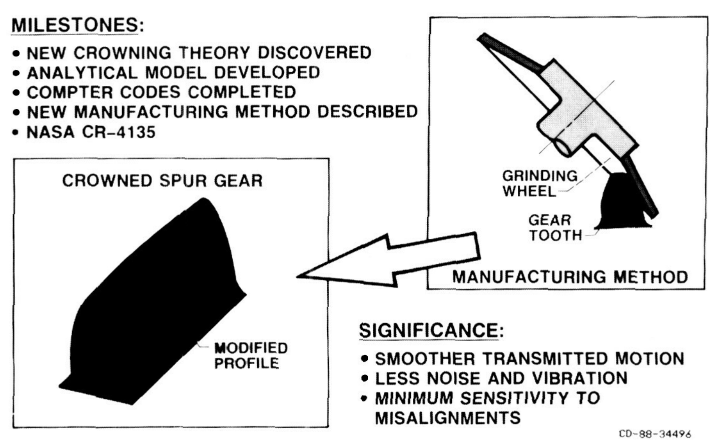
Current practice is to compensate for the edge loading by putting a slight crown on the teeth during the grinding process. The crowning will prevent the tooth load from moving to the edge of the tooth if the gears become misaligned. The current method of crowning does a good job of preventing edge loading, but the gears are still noisy when misaligned because conventionally crowned gears do not transmit motion smoothly. A new crowning technique was needed that would continue to avoid edge loading while reducing the vibration and noise when the gears have to operate with misaligned shaft axes. A grant was thus established at the University of Illinois at Chicago (Dr. Faydor L. Litvin, principal investigator). The mathematical principles of gear meshing were applied to find the type of gear tooth crowning least sensitive to misalignments. A new concept for crowning spur gear teeth was discovered. The concept is supported by rigorously applying the mathematics of tooth meshing theory. The analysis has been coded into a computer program for tooth contact analysis that calculates the tooth load distribution and the motion errors causing vibration and noise. With this program one can select the best crowning geometry to compensate for a range of misalignment.

The crowning can be produced by either of two grinding methods: (1) using a five-axis numerically controlled machine with a flat grinding wheel or, (2) using a conventional gear grinding machine with a grinding wheel that is basically cone shaped but with a slight curvature to the cone element.

The new crowning technique benefits aircraft applications, where light weight is important. The crowning compensates for misaligned conditions of the shaft axes and is minimally sensitive to variation in misalignment. Smoother motion is transmitted between shafts. The benefit is less noise and vibration while maintaining light weight and long life.

Lewis contact: Robert F. Handschuh, (216) 433–3915
Headquarters program office: OAST

Improved spur gears for aircraft applications



Supersonic Throughflow Fan

NASA Lewis has embarked on a program of experimental and analytical research in order to demonstrate compression systems at design and off-design conditions. The aerodynamic design of a supersonic throughflow fan by using advanced computational codes was accomplished last year. The design pressure ratio was 2.45 at a tip speed of 1500 ft/sec. The design inlet Mach number was 2.0. The mechanical design and fabrication of the rotor were completed this year. The 20-in.-diameter rotor has a hub-tip ratio of 0.7.

Analysis of the supersonic throughflow fan has continued. An unsteady Euler analysis indicated that the interactive supersonic wave patterns within and exiting the rotor result in a time-dependent flow field entering the stator. The wave motion is nonlinear, with more energy being added when the shock moves forward than is substracted when the shock moves rearward.

To obtain data with which to verify the quasi-three-dimensional, thin-shear-layer Navier-Stokes code used in the design procedure, we performed a cascade test on an airfoil that corresponds to the rotor mid-passage section. Preliminary schlieren results indicate that the code predicted the shock patterns reasonably well.

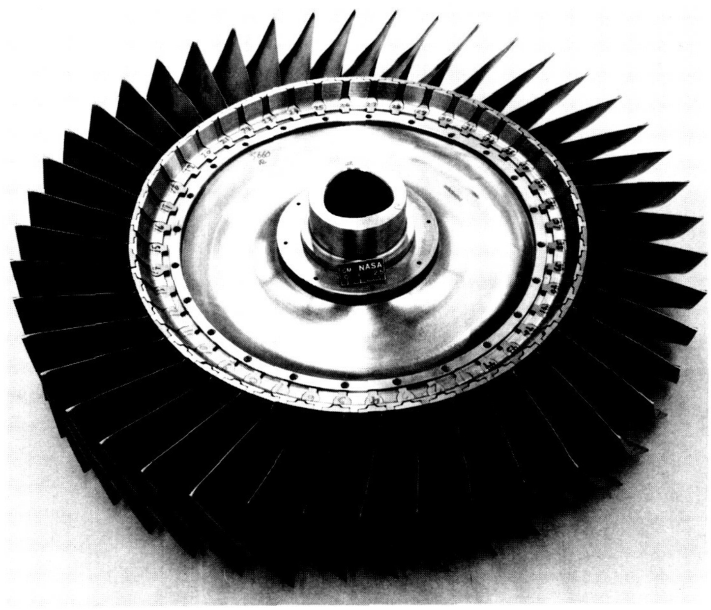
An existing multistage compressor facility has been extensively modified for testing the supersonic throughflow fan. Dry air capability and a vacuum bleed system were major additions to the test facility. A variable inlet nozzle to vary the inlet Mach number and a variable exit diffuser to diffuse the supersonic exit flow to subsonic conditions were also installed. The facility, which will become operational in early 1989, will provide a unique opportunity to test supersonic throughflow compression systems.

Bibliography

Ball, C.L.; and Moore, R.D.: Supersonic Throughflow Fans. Transonic Compressors, VKI-LS-1988-03, Von Karman Institute for Fluid Dynamics, Rhode-Saint-Genese, Belgium, 1988.

Lewis contact: James F. Schmidt, (216) 433-3594
Headquarters program office: OAST

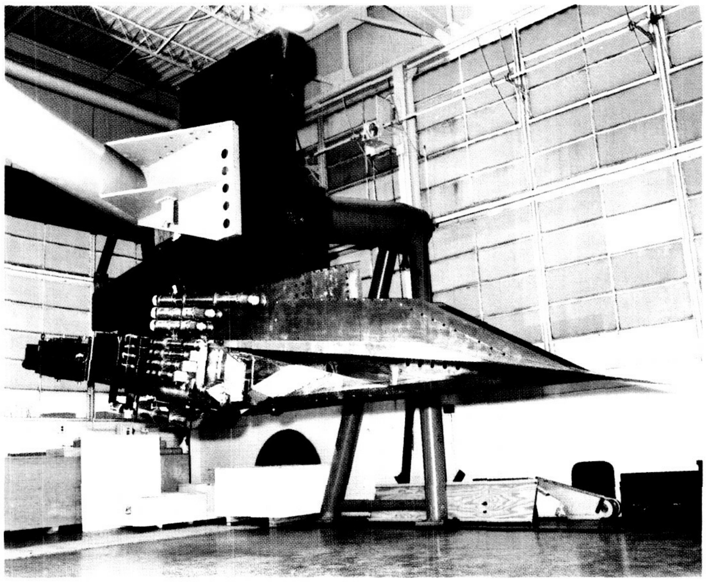
Supersonic throughflow fan



Mach 5 Cruise Inlet

During a joint research study NASA (Lewis and Langley) and industry (Lockheed and Pratt & Whitney) have identified an "over-under" turbojet plus ramjet as a viable propulsion system for a Mach 5 cruise aircraft. This propulsion system has been designed to operate over the entire speed range from 0 to Mach 5. Lockheed and Pratt & Whitney designed and integrated the propulsion system, provided a conceptual design of the aircraft with realistic propulsion and airframe weights, designed and analyzed the propulsion system's cooling system, and evaluated the performance potential of this class of aircraft. The NASA research work provided new ideas in such areas as propulsion integration, structures, and inlet and nozzle design and sought to experimentally validate those concepts that appeared to be practical from a design viewpoint.

As a result of the high-speed study effort the ramjet inlet from the over-under turbojet-ramjet propulsion system is to be tested in the Lewis 10- by 10-Foot Supersonic Wind Tunnel. This large inlet incorporates a variable ramp system, from Mach 3 to Mach 5 (ramjet operating speeds), and remotely variable mass-flow plug systems for the main duct and bleed systems. The model has been extensively instrumented to provide validation data for computational fluid dynamics codes in addition to inlet performance information. So that the Mach 5 design can be tested in this facility, which has a maximum Mach number capability of 3.5, a 1/3-scale model is to be mounted under a large plate at negative angle of attack. By this means the Mach 3.5 flow will be expanded to the desired speed of Mach 4.1 on the first ramp. The inlet for the test program was designed by using a conventional method of characteristics approach with a boundary layer correction.



Mach 5 cruise inlet model

Supporting research studies for the inlet program include flow field prediction with a three-dimensional viscous analytical code (PEPSIS) and small-scale inlet testing in the Lewis 1- by 1-Foot Supersonic Wind Tunnel. The analytical studies have indicated a significant boundary layer flow migration on the sidewalls from the ramp toward the inlet cowl. This low-energy airflow is captured by the inlet and results in a separated flow region in the corners of the cowl. Such separations generally lead to inlet unstart and are thus a major concern. The small-scale data verify the flow migration on the sidewalls. As a result additional bleed regions have been added to the inlet model sidewalls and cowl to control the separation.

An inlet model was mounted in the Lewis 10- by 10-Foot Supersonic Wind Tunnel for testing starting in October 1988. The inlet was mounted below the accelerator plate, and the internal flow passage was rectangular from capture to the main exit plug. Bleed flow control piping and plugs were attached to the side of the model.

Lewis contact: Robert E. Coltrin, (216) 433-2181
Headquarters program office: OAST

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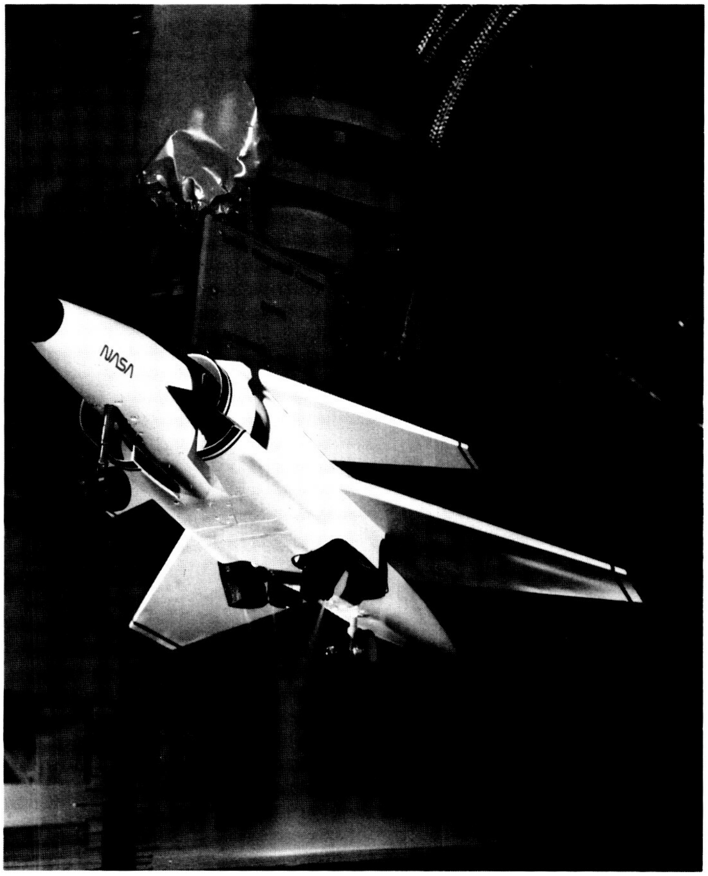
STOVL Hot Gas Ingestion Testing

Advanced short takeoff and vertical landing (STOVL) fighter/attack aircraft capable of operating from remote sites or damaged runways are being studied for possible deployment around the turn of the century. Hot gas ingestion (HGI) is a key development issue since STOVL aircraft operating near the ground are subject to significant thrust losses due to the ingestion of hot exhaust gases. NASA Lewis, McDonnell-Douglas Aircraft, and the Defense Advanced Research Projects Agency defined a cooperative program for testing in the Lewis 9- by 15-Foot Low-Speed Wind Tunnel to establish a data base for HGI. The HGI test program consisted of a 9.2-percent scale model, noted as 279–3. The modeled vectored-thrust aircraft concept consisted of a single engine, a bifurcated inlet, auxiliary inlets, and four nozzles—two forward and two aft. Hot gas ingestion testing was accomplished over a headwind range of 5 to 90 knots and a temperature range of ambient to 500 °F. A trap door, a trap door scavenging system, and a sidewall scavenging system were used to prevent recirculation of the hot gases within the test section. The test environment thus clearly simulated the actual flight environment. The exhaust nozzle flow patterns were observed by using a water flow visualization system developed for this test. A water mist was injected into the ambient temperature air supply plenum for each of the four nozzles. The visualization was recorded on motion picture film and on video cassette tape.



STOVL aircraft model 279–3 in low-speed wind tunnel

This wind tunnel test resulted in several important findings. The interactions between the nozzle jets and the ground occurred at lower main wheel heights above the ground than expected. Lift improvement devices were highly effective in controlling the near-field ingestion. Also, changing the nozzle splay angle further reduced HGI. It became apparent in this testing that each aircraft concept will probably be subject to HGI to some degree. However, there are in turn many possible solutions available to limit HGI; the choice of which solution to use will depend on the individual geometry of the aircraft. A very important data base has been established for supersonic jets with several nozzle arrangements exhausting in a subsonic environment. The data base includes compressor face pressure and temperature contours, distortions with ground plane measurements, and flow visualization.

Bibliography

Johns, A.L., et al.: A Vectored Thrust STOVL Concept With Flow Visualization in the NASA Lewis 9′ by 15′ Low Speed Wind Tunnel. AIAA Paper 88–3025, July 1988.

Strock, T.W.; Amuedo, K.C.; and Flood, J.D.: Hot Gas Ingestion Test Program Results, Phase I. NASA CR–182115, 1988.

Lewis contacts: Albert J. Johns, (216) 433–3972; George H. Neiner, (216) 433–5661
Headquarters program office: OAST

Initial Full-Scale Ejector Test

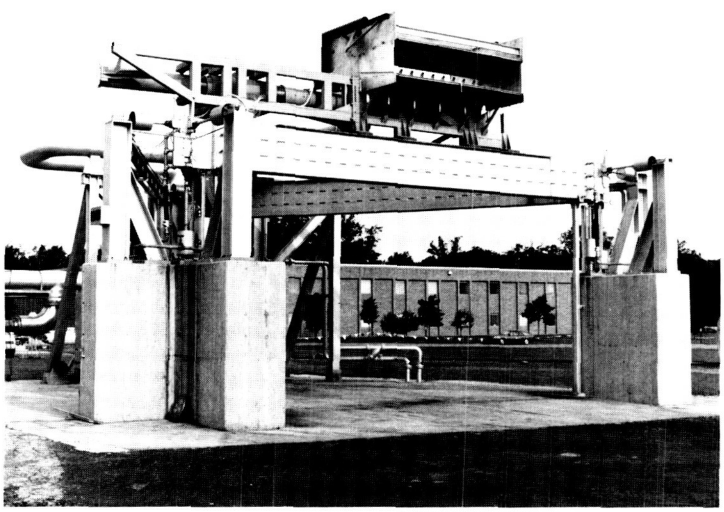
This full-scale ejector test is one of a series of tests to be conducted at NASA Lewis as part of the U.S./Canada Ejector Supersonic Short Takeoff and Vertical Landing (STOVL) Technology Program. DeHavilland Aircraft Company of Canada is presently contracted by the Canadian Government to design and build a full-scale wind tunnel model of the GD E–7 STOVL fighter aircraft, which includes two forward ejector lift/thrust concepts also designed by deHavilland. The E–7 model was tested in NASA Ames 40- by 80-Foot Wind Tunnel in 1988. Lewis was chosen as the ejector test site because of its ongoing lead role in VSTOL propulsion and its unique capabilities of providing a large continuous source of high-pressure air and flow for fan discharge simulation. Before the Ames wind tunnel test could be conducted, this ejector concept had to satisfactorily meet the E–7 model thrust augmentation requirements.

The full-scale E–7 ejector/Spey system was evaluated on the Powered Lift Facility (PLF). This unique new facility enables NASA Lewis researchers to develop and validate the technology for supersonic STOVL aircraft propulsion concepts. The E–7 ejector/Spey system includes an engine bypass fan air supply off-take plenum, forward and rear ducting, valving, and the ejector. Prior to the subject test an airflow pressure loss evaluation of this system without the ejector was conducted on the PLF. Facility supplied airflow simulated the Spey engine bypass fan discharge flow rates and pressure. The full-scale ejector test hardware was then evaluated with the same ducting. The test hardware was installed horizontally on the 30-ft triangular thrust frame of the PLF. The rectangular "box-like" ejector has 12 sets of three primary nozzles. The fuselage and wing side contours were simulated as well as "flightlike" doors, seals, and hinges. The ejector test hardware was evaluated with heated facility air up to 760 °R and at nozzle pressure ratios from 1.4 to 3.0. Thrust, airflow, pressures, and temperature were measured.

Results of both the previous deHavilland tests of the partial system and the current Lewis tests indicate a high level of confidence in the projected performance of the ejector system installed in the full-scale E–7 wind tunnel model. These results, combined with other previous successful results from a scaled ejector/wing model tested in the Lewis 9- by 15-Foot Low-Speed Wind Tunnel and the Langley 4- by 7-Meter Low-Speed Wind Tunnel increased the overall confidence level in the ejector augmentor concept. The ejector concept is one of the four propulsive lift concepts being considered for study in the U.S./U.K. ASTOVL fighter aircraft program.

Lewis contact: Rudolph E. Grey, (216) 433–3958
Headquarters program office: OAST

Ejector test hardware installed on PLF



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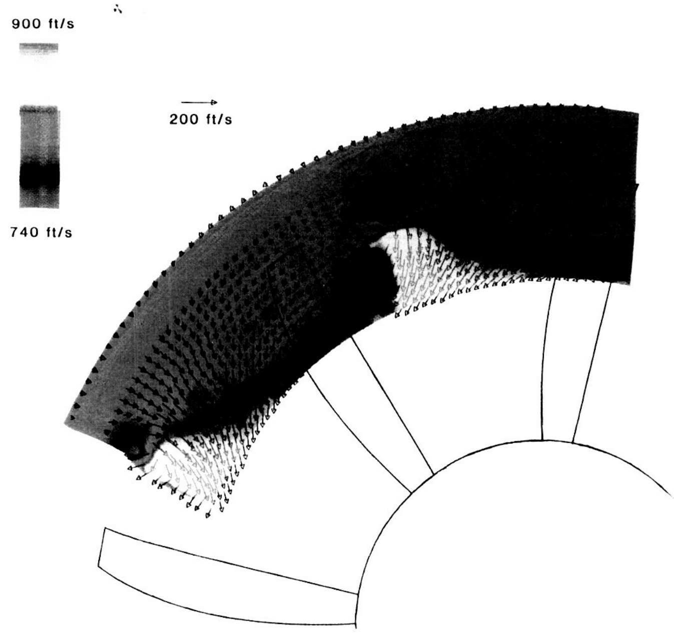
Laser Velocimeter Measurements of Advanced Counter-rotation Propeller Flow Field

A better fundamental understanding of the flow fields generated by advanced turboprop models can lead to future propeller designs that outperform those presently available. Computer codes developed to predict these highly complex flow fields must be validated with detailed experimental data. Such data were acquired at NASA Lewis by using a two-component laser Doppler velocimeter to make nonintrusive optical measurements of the velocity field generated by a 2-ft-diameter counterrotating propeller model. This test was conducted in the Lewis 8- by 6-Foot Wind Tunnel with the model operating near its design cruise condition at a free-stream Mach number of 0.72 and with the advance ratio of each rotor set at 2.80.



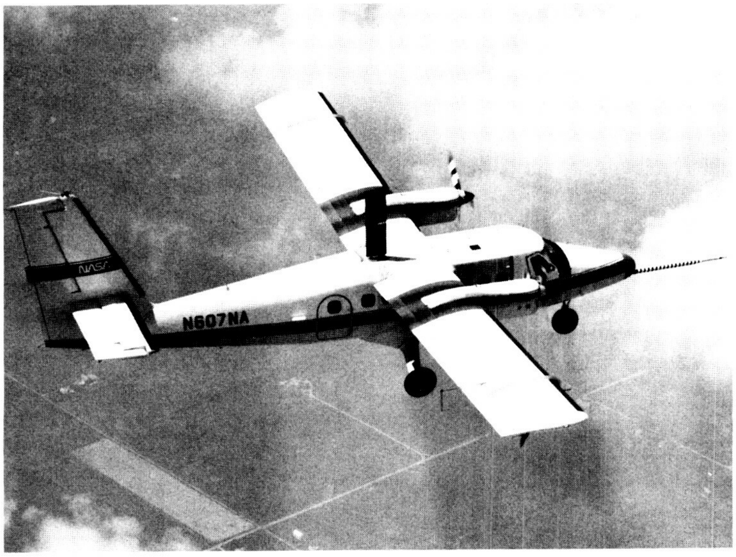
Laser velocimeter measurements downstream of front rotor, showing tip vortices

The velocity data were acquired at one constant axial station upstream of the front rotor, at five axial stations between the two rotors, and at three axial stations downstream of the aft rotor. The upstream data show a circumferentially uniform inflow into the front rotor and the acceleration of the flow over the nacelle. Data obtained between the two rotors show the turning of the flow caused by the rotating blades and large gradients in velocity occurring across the blade wakes. The gradual development of tip vortices with increased distance downstream of the front rotor blades was also observed. The data indicate that a portion of these vortices will be intercepted by the downstream rotor blades and thereby can be expected to contribute to the interaction noise generated by this configuration. Velocities measured downstream of the second rotor show that for the conditions set during this test only about half of the swirl imparted to the flow at outer spanwise locations by the upstream rotor is removed by the aft rotor.

Lewis contact: Gary G. Podboy, (216) 433-3916
Headquarters program office: OAST

Heat Transfer to Smooth and Roughened Airfoils in Flight and in a Wind Tunnel

Wind tunnels typically have higher free-stream turbulence levels than are found in flight. Turbulence intensity has been measured to be 0.5 percent in the NASA Lewis Icing Research Tunnel with the cloud-making sprays off. Turbulence intensity for smooth-air flight conditions was found to be too low for meaningful measurements (<0.1 percent). This difference between free-stream and wind tunnel conditions has raised questions as to the validity of results obtained in the Icing Research Tunnel. Tests were therefore conducted to determine the effect of free-stream turbulence



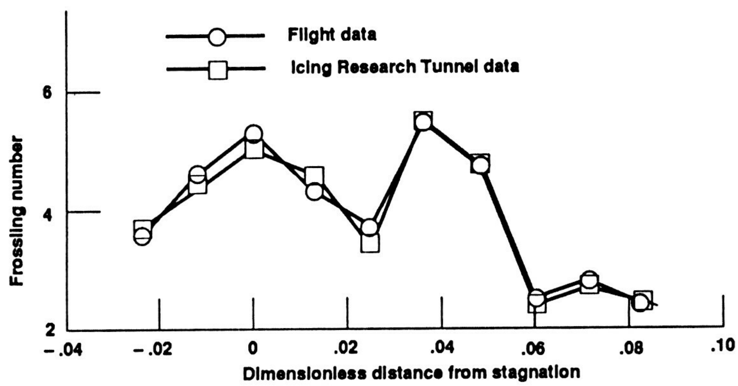
Twin Otter icing research aircraft

on convective heat transfer to a smooth and a roughened airfoil. Another objective was to obtain needed heat transfer data for the NASA Lewis LEWICE ice growth prediction code for both smooth and roughened airfoil surfaces.

Data were provided on heat transfer from an NACA–0012 airfoil with a 533-cm (21-in.) chord for both in-flight and wind tunnel conditions. Heat transfer measurements were recorded in flight on the NASA Lewis Twin Otter icing research aircraft. Wind tunnel data were obtained in the Icing Research Tunnel with and without icing cloud spray nozzle atomizing air. Roughness was obtained by attaching small (2-mm diameter) hemispheres of uniform size to the airfoil in four different patterns. Measurements were taken for the smooth and roughened surfaces at various airspeeds and at angles of attack up to 6°. Results were presented as Frössling number (dimensionless heat transfer coefficient divided by the square root of Reynolds number) versus position on the airfoil for various roughnesses and angles of attack.

Comparing heat transfer results with no icing cloud present showed no measurable difference between the flight and wind tunnel data at low Reynolds numbers (1.2 million) and only slightly more scatter at high

Heat transfer measurements on airfoil with dense roughness pattern at Reynolds number of 1.2 million



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Reynolds numbers (2.4 million). Operating the Icing Research Tunnel with nozzle atomizing air on also made no measurable difference in heat transfer, indicating that this portion of the cloud-making equipment did not increase test section turbulence. Heat transfer data were obtained for both a smooth surface and a roughened surface airfoil and can be incorporated in various ice growth prediction codes.

This work was performed in-house with the assistance of personnel from the University of Toledo.

Bibliography

Newton, J.E.; et al.: Measurement of Local Convective Heat Transfer Coefficients From a Smooth and Roughened NACA-0012 Airfoil: Flight Test Data. AIAA Paper 88-0287, Jan. 1988. (NASA TM-100284.)

Lewis contact: Dr. James VanFossen, Jr., (216) 433-5892
Headquarters program office: OAST

SR-5 propfan blade

Design and Analysis of SR-5 Propfan Blade Structure

NASA Lewis has developed special in-house processes for manufacturing fiber-reinforced polymer matrix composite primary structures such as propfan blades. These processes are closely controlled in order to obtain predictable structural properties and finishes. In the fall of 1987, graphite-filament-epoxy-matrix propfan blades were built and successfully tested in the Lewis 8- by 6-Foot Wind Tunnel.

Model dynamic analysis capabilities have been verified by holography tests on fabricated blading. Stress and deflection analysis and test correlations are planned in the near future. Two SR-5 propfan blades will be tested in a spin test rig. The special-purpose Lewis-developed codes currently being used in conjunction with MSC/NASTRAN for the composite structural analysis are COBSTRAN, ASTROP2, and STAT.

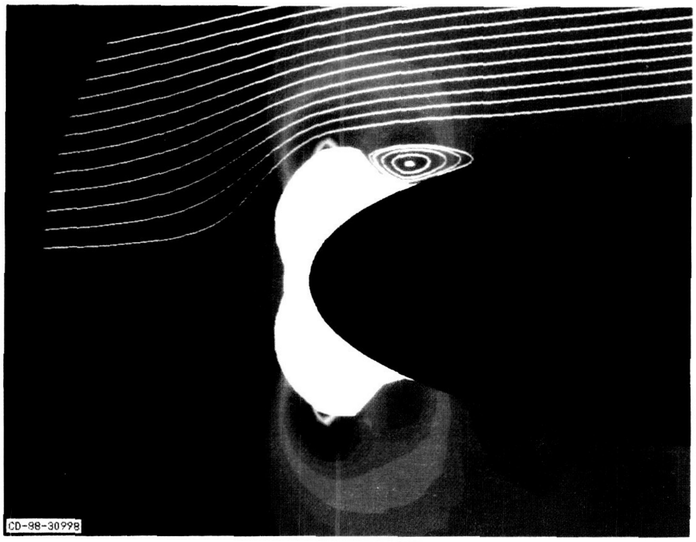
Lewis contact: Delmar W. Drier, (216) 433-3825
Headquarters program office: OAST

Icing

Airfoil Icing Analysis

The NASA Lewis Aircraft Icing Analysis Program is composed of three major subprograms: ice accretion simulation, performance degradation evaluation, and ice protection system evaluation. These topics cover all areas of concern related to the simulation of aircraft icing and its consequences. The motivation for this program is twofold: reducing the time and effort required in experimental programs, and acquiring the ability to provide reliable information for aircraft certification in icing over the complete range of environmental conditions. In addition to the analytical activities associated with developing simulation codes, several experimental programs are also investigating the physical processes associated with ice accretion and removal so that present analytical models can be improved. The Aircraft Icing Analysis Program is thus striving to provide a full range of validated analytical tools for evaluating the consequences of icing and ice protection systems.

Two of these tools were recently used to produce a computational evaluation of the ice accretion process and the resulting performance changes for an NACA–0012 airfoil. The ice accretion code, LEWICE, provided the ice accretion buildup during the simulated icing encounter. The predicted shapes are a function of several environmental input parameters, including airspeed, temperature, water droplet size and distribution, liquid water content, and duration of the encounter. These ice shape geometries are then input into a Navier-Stokes analysis code, ARC2D, which calculates the flow field and determines changes in airfoil performance characteristics. One of the objectives of the icing analysis program is to combine codes such as these into a comprehensive icing analysis method.



Simulation of icing on NACA–0012 airfoil: angle of attack, 0°; Mach 0.3; Reynolds number, 3 million

Lewis contact: John J. Reinmann, (216) 433–3900
Headquarters program office: OAST

Facilities

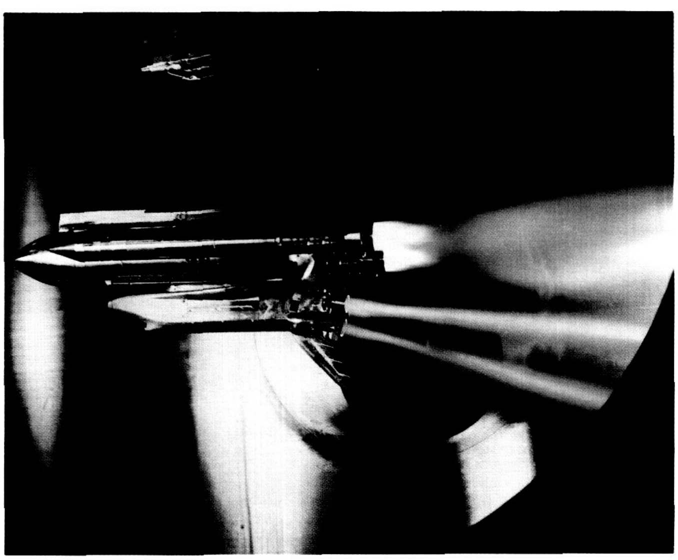
Space Shuttle Engine-Out Loads Test

A series of tests were run in the NASA Lewis 10- by 10-Foot Supersonic Wind Tunnel to verify the aerodynamic effects of the loss of one or more space shuttle main engines (SSME). The model provided for this test was a 0.0225 scale replica of the space shuttle integrated vehicle. The model could simulate a short-duration (50 to 80 msec) plume by burning oxygen and hydrogen in the orbiter engines and a gaseous equivalent propellant combination in the solid rocket booster engines.

The model-related measurements required for this test included 199 model surface pressures, propellant supply charge tube pressures and temperatures, combustion system internal pressures, model cavities temperatures, propellant position, and events sequence timing. The dynamic surface pressures were used to calculate the air loads on the vehicle for each engine-out configuration. The other pressures and temperatures were used for system setup and control room monitoring during each test.

The test schedule was extremely important because acquiring these data was a constraint on placing the shuttle back into service. An estimated 14-week test program at Lewis was completed in less than 9 weeks. Post-test data analysis showed the air loads on the shuttle vehicle caused by the loss of an SSME engine to be the same or less than the pretest analytically estimated loads. Therefore there is no need to apply additional shuttle launch restraints as a precaution for a possible SSME failure.

Lewis contact: Kenneth L. Baskin, (216) 433-5666
Headquarters program office: OAST



Space shuttle engine-out loads test showing main and booster engines operating

Large, Low-Speed Centrifugal Compressor

Centrifugal compressors find their application in relatively small propulsion systems for such vehicles as helicopters and small business jets. They become attractive at these small sizes because of their potential for higher performance, greater reliability, and lower initial cost than small axial compressor systems.

Efforts are currently under way to develop computational techniques for analyzing the flow field within centrifugal compressors. This flow field is extremely complex and includes such features as relatively thick blade surface and endwall boundary layers, strong secondary flows, hub and tip corner vortices, and shock waves. An important part of developing these computational techniques is the execution of detailed flow physics experiments with centrifugal

Large, low-speed centrifugal compressor compared with hand-held "full-size" centrifugal compressor

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compressors to develop insight into these various flow features, to obtain data for the development of flow models necessary in the analyses, and to provide accurate, detailed data sets for validating computational methods.

Because full-size centrifugal compressors are relatively small, the experimental test hardware must be scaled up to sizes where the flow features become large enough to permit making the necessary measurements and where the blockage of the measuring probes is not excessive. Such a large centrifugal compressor, with an inlet diameter of about 3 ft and an exit diameter of 5 ft, has been developed and is nearly research operational. At the compressor exit plane the blade height is about 6 in., and throughout the compressor the geometry is large enough to permit the measurement of detailed flow features.

The facility has been operated to full speed driving a dummy aluminum rotor. All the support systems, the drive motor, the gearbox, the bearings, the controls, the data systems, and the safety systems have been thoroughly checked out. During checkout of the real rotor it was found that the instrumentation wiring could not withstand the high g loads. Advanced wire bonding techniques have now been applied to the rotor and it is being reinstalled in the facility. Checkout was completed in September 1988.

Lewis contact: Alvin E. Buggele, (216) 433-5675
Headquarters program office: OAST

New Direct-Connect, Continuous-Flow Facility Capable of True Mach 6 Flight Simulation

Renewed interest in hypersonic propulsion has provided the impetus to expand the research facility capability within NASA. Test cell 4 of the Propulsion Systems Laboratory (PSL) at NASA Lewis has been modified to provide Mach 6 direct-connect testing capability. The palletized modular design concept allows the facility to be configured for Mach 6 testing or returned to its standard engine testing configuration as research programs dictate.

In a direct-connect facility the total pressure and temperature of air supplied to the face of an engine must match the stagnation conditions that would be supplied by the actual vehicle inlet system at the flight condition being simulated. The PSL hypersonic

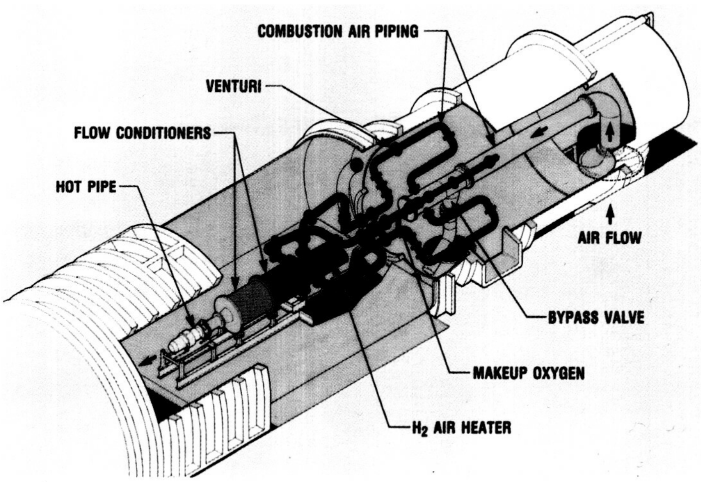
modification can properly simulate Mach 6 flight at altitudes above 100,000 feet by conditioning the inlet air to pressures up to 100 psia and temperatures up to 3000 °F. Inlet temperature conditioning is provided by a gaseous-hydrogen-fueled vitiating air heater that incorporates a provision for correcting the oxygen content of the air supplied to the test article.

All facility support systems remain functional, including thrust measurement capability, a 1200-channel steady-state data system, and a 250-channel high-speed digital data system. In addition to common JP fuels and high-pressure methane, gaseous hydrogen and gaseous oxygen, both at 1000 psia, are available to the test article at flow rates up to 2.75 and 3.0 lb/sec, respectively. Engine air mass flows up to 80 lb/sec are possible.

The facility is currently engaged in acceptance testing in which a hollow pipe (the "hot pipe") with various standard nozzles is installed in place of an engine to calibrate the flow characteristics of the facility. Extensive inlet instrumentation has been installed to allow tailoring and documentation of inlet flow quality.

This facility is unique by virtue of its ability to provide true simulation of Mach 6 flight in a continuous-flow operating mode (limited only by propellant storage) and will be an asset to hypersonic propulsion system research.

Lewis contact: John H. Dicus, (216) 433–5720
Headquarters program office: OAST



PSL–4 hypersonic modification—direct-connect research rig

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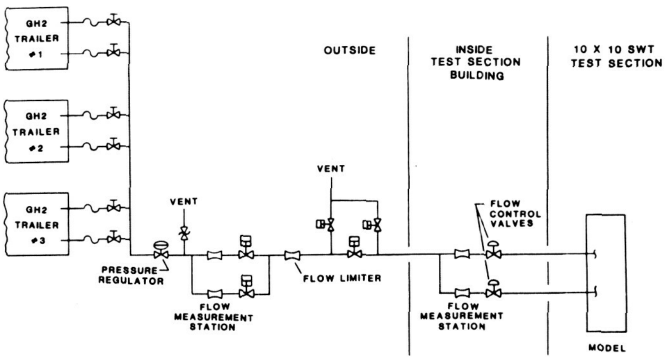
New Gaseous Hydrogen System Increases Wind Tunnel Testing Capabilities

A new gaseous hydrogen system has been installed in the NASA Lewis 10- by 10-Foot Supersonic Wind Tunnel. The system is designed to provide conditioned gaseous hydrogen as a fuel for testing propulsion models in the wind tunnel. The new system was used initially for testing propulsion system concepts in support of the National Aerospace Plane (NASP) Program. In a recently completed program the system was used successfully to provide fuel to the baseline module of the Government concept of the NASP engine. The addition of this gaseous hydrogen system creates a unique facility for propulsion testing in the United States.

The system can deliver gaseous hydrogen to a model at the



Gaseous hydrogen system for 10- by 10-Foot Supersonic Wind Tunnel

following maximum conditions: 0.6-lb/sec flow at 1200-psig pressure and ambient temperature. Up to three trailers (2200 psig, 70,000 std ft^3 each) can be used as the source, making approximately 500 lb of gaseous hydrogen available for testing at maximum pressure. Dual-flow measuring stations with venturi flowmeters provide backup flow measurement capability. One station measures the total flow from the trailers. The second station measures the flow in the individual model supply lines. The main supply line is divided into two model supply lines, each having a flow control valve to independently control gaseous hydrogen flow to two model injection areas. A regulator in the main supply line controls pressure upstream of the flow control valves.

Modifications to the system are currently being designed that will increase flow rates and add the capability of flowing gaseous hydrogen at temperatures up to 1300 °F. These are required to support planned testing of another generation of NASP engine models beginning in 1989. The modified system will have two main supply lines to the wind tunnel. One line will be capable of flowing only ambient-temperature gaseous hydrogen; the other line will be able to flow gaseous hydrogen at temperatures from ambient up to 1300 °F. Initial testing with hot hydrogen will use a pair of hydrogen heaters being designed by Rocketdyne.

A gaseous hydrogen detector system was also installed in the wind tunnel facility to monitor any leakage. Eight sensors located throughout the wind tunnel, the test section building, and the trailer storage area are monitored centrally in the tunnel control room.

The hydrogen system has been placed under the Lewis Research Center Recertification Program. This ongoing program ensures continued quality and integrity for hazardous systems through regular, thorough, periodic inspections. This is an important and necessary step in preserving this national capability.

Lewis contact: James W. Roeder, Jr., (216) 433-5677
Headquarters program office: OAST

Rehabilitation of Control Room for 8- by 6-Foot Supersonic Wind Tunnel

The NASA Lewis 8- by 6-Foot Supersonic Wind Tunnel was constructed in 1948. During the early 1960's the return leg of the tunnel was converted into a low-speed wind tunnel, known as the 9- by 15-Foot Low-Speed Wind Tunnel. The overcrowded original control room for the supersonic tunnel has served to control both facilities as well as the auxiliary services and dual data acquisition systems required for models in both tunnels. This control room is being extensively rehabilitated. Its size has nearly doubled and provision has been made for setting up each facility independently for consecutive tunnel runs during the same day.

The room can be split into two separate rooms via a moving wall. The control room modification includes a state-of-the-art,

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microprocessor-based distributed control system manufactured by the Westinghouse Corporation. The Westinghouse Distributed Process Family (WDPF) system allows the operators to fully monitor and control the facility through interactive colorgraphic cathode-ray-tube stations. Automatic following of trends and logging of facility operating parameters is available, as well as a digital closed-loop control system. The WDPF system consists of two operator consoles configured such that, when the room is split, one console can control the supersonic wind tunnel while the other controls the low-speed wind tunnel or, when the room is one large room, both consoles can be used for either facility. Each console contains two keyboards and three high-resolution color cathode ray tubes, with associated printers.

A historical data storage and retrieval unit continuously records control actions. At any time these data can be retrieved to provide a time history of all control actions for a tunnel run. The data can be transcribed onto magnetic tape for long-term storage. All systems are backed up by a dual fiber optic data highway and dual digital processing units. The control system has bumpless transfer from manual to automatic and back and has easily changeable tuning conditions for control loop process points. The new control system provides the capability to correlate tunnel operations with research requirements, virtually on-line.

Lewis contacts: Frank J. Paulovich, (216) 433–5692; Douglas Dolch, (216) 433–5449
Headquarters progam office: OAST

Rebabilitated control room

Hypersonic Direct-Connect Research Rig

In 1985 NASA Lewis realized the need for a Mach 3 to 6 direct-connect testing capability. As a result, the Propulsion Systems Laboratory 4 was modified. The modifications were based on the requirements of an air-turbo-ramjet proof-of-concept demonstrator. The facility can now test a variety of hypersonic engines and engine components in either a direct-connect or free-jet configuration.

Four major modifications were made to the facility. The combustion air supply and the inlet plenum were modified to accommodate the full 150-psig supply pressure. A large four-burner, gaseous-hydrogen-fired air heater was procured and installed to provide up to 3000 °F air at the engine inlet. The existing gaseous hydrogen and nitrogen supply systems were modified, and a new gaseous oxygen system was installed. A significant amount of hardware was fabricated to instrument and condition the flow into the engine. All of these modifications can be removed and the facility can be returned to its previous configuration for testing engines requiring low inlet pressure and high flow rates.

The systems testing was performed in September and October of 1988. The facility is now capable of testing engines to Mach 6 simulated flight conditions for runs of 30 to 60 minutes.

Lewis contact: Brian D. Blue, (216) 433–3801
Headquarters program office: OAST

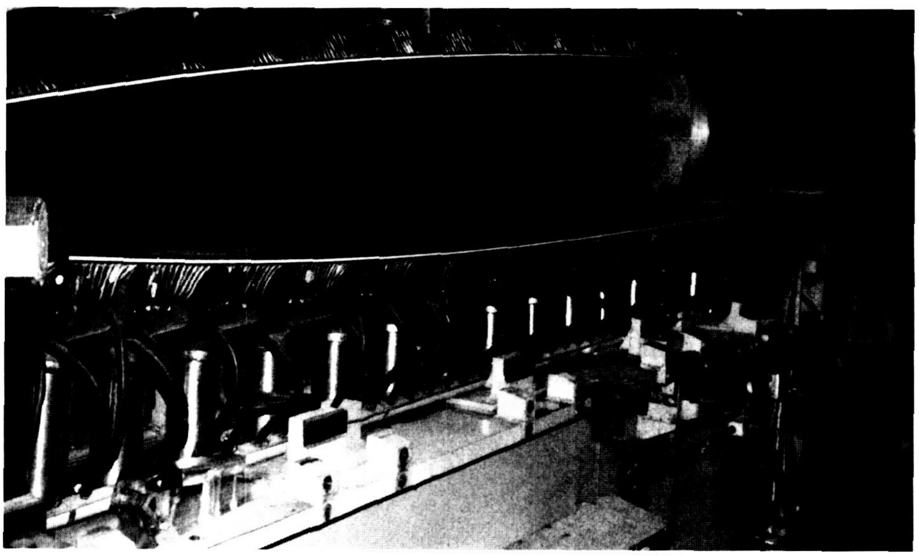
JPL'S Hypersonic Wind Tunnel Moved to Lewis

NASA Lewis is expanding its hypersonic testing capabilities for aeropropulsion research in the 21st century by relocating the Jet Propulsion Laboratory's (JPL) 21-In. Hypersonic Wind Tunnel to Lewis. The first step in the process, a $2 million project for dismantling and trucking the tunnel components from California to Ohio, was completed in fiscal 1988. The next step will be reassembly of the tunnel on a site to be selected at Lewis.

Major tunnel components that were moved included four compressors, the air heater, diffusers, the test section, the flexible-wall section, the aftercooler, heat exchangers, pumps, and the lubricating system. The components will be stored temporarily at the Plum Brook Station in Sandusky, Ohio.

Studies are being performed to select a permanent site at Lewis that will optimize use of existing central systems and equipment. A preliminary engineering study will be done in fiscal 1989 to establish the scope and cost for construction in fiscal 1991.

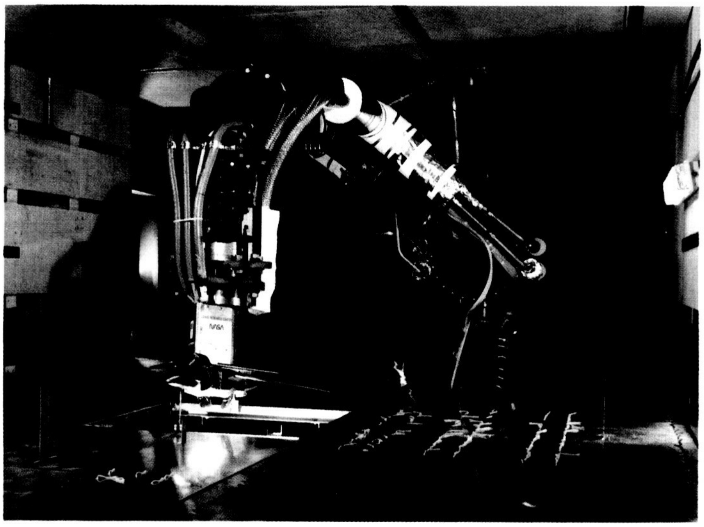
Lewis contacts: Paul Weisenbach, (216) 433-5459; Jeffrey E. Haas, (216) 433-5718
Headquarters program office: OAST



21-In. Hypersonic Wind Tunnel

Hot Gas Ingestion Testing In Low-Speed Wind Tunnel

Hot gas ingestion testing of a propulsion system in a wind tunnel environment was successfully demonstrated in the NASA Lewis 9- by 15-Foot Low-Speed Wind Tunnel. The speed range was 5 to 90 knots and the temperature range was ambient to 500 °F. A trap door, a trap door scavenging system, and a sidewall scavenging system were used to prevent recirculation of the hot gases within the test section. Thus the test environment clearly simulated the actual flight environment. The design of these systems was a critical factor in the success of the test program.



Hot gas ingestion model and support system in low-speed wind tunnel

The runway was simulated by a fixed ground plane extending from one tunnel wall to the other and from the front of the test section to a point beyond the model almost to the end of the test section. The ground plane was 2 ft off the tunnel floor. It contained a translating trap door located right under the model for achieving proper flow conditions before taking data. The trap door scavenging system used a 125-psi air ejector system to pump the nozzle hot gases going into the open trap door to a point just beyond the ground plane. These gases were pumped down a duct located between the ground plane and the tunnel floor. The sequence of operations was as follows: First the trap door was left open until the flow conditions were established. Then, before data were taken, the trap door was closed (less than 0.5 sec) and the trap door scavenging system was turned off.

This procedure was repeated for each set of operating point conditions. The sidewall scavenging system used the natural tunnel flow to move the hot gases out of the test section. The hot gases were mixed with cooler air and then injected back into the wind tunnel at a point downstream of the model. The exhaust nozzle flow patterns were observed by using a water flow visualization system developed for this test. A water mist was injected into the ambient-temperature air supply plenum for each of the four nozzles. The visualization was recorded on motion picture film and on a video cassette recorder, either a single or split screen.

Lewis contact: George H. Neiner, (216) 433-5661
Headquarters program office: OAST

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Space Propulsion

Strategic Objectives

- To remain in the forefront as a major NASA center for space propulsion R&T required to meet current and future national needs for space.

- To capture development responsibility for the next-generation space hydrogen-oxygen (H/O) engine for orbit transfer vehicles, upper stages, Mars/lunar transfers, etc., and to vertically integrate our research and technology with system development activities.

Programs

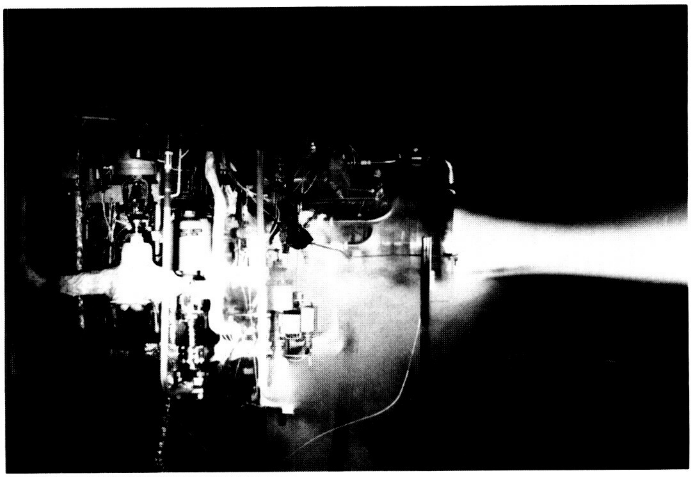
Space Transfer Engine

The NASA Lewis plan for the space transfer engine will ensure the successful development of the propulsion technology for high-performance, space-based orbit transfer vehicles as well as for lunar and Mars transfer vehicles. The program will focus on developing a validated design and analysis data base for high-performance, fault-tolerant, liquid oxygen-hydrogen engines with in-space maintainability and automated operations. Breadboard engine demonstrations will be a key part of the effort. Following the breadboard demonstration will be an engine development and system integration effort culminating in a deliverable, validated engine system for potential users.

Considerable progress has been made in fiscal 1988 in the pursuit of these R&T goals. The more prominent of these accomplishments are listed here.

Performance and heat transfer tests of the 3000-lb-thrust annular thrust chamber.—An annular thrust chamber was designed, built, and tested over a chamber pressure range of 100 to 2000 psia and a mixture ratio range of 3 to 8. Heat flux measurements were obtained on the combustion chamber walls.

Preliminary design of the 7500-lb-thrust engine.—Two preliminary orbit transfer vehicle engine designs, with different expander cycles, have been completed. Preliminary descriptions and operating characteristics are now available. This provides a firm foundation for the next step in the space transfer engine technology program.



Test firing of experimental cryogen-fueled rocket engine

Boundary layer development in a 1030:1 area ratio rocket nozzle.—The objective was to determine the combustion chamber pressure at which the flow in the 1030:1 nozzle can be considered to be laminar and the pressure at which it will be turbulent. Hot fire tests were performed at altitude over a range of chamber pressures from 350 to 1000 psia.

Lewis contact: Albert J. Pavli, (216) 433–2470
Headquarters program office: OAST

Launch Vehicle Project Office Works to Commercialize Space

The Launch Vehicle Project Office has made significant progress during the past year in two efforts directed at commercializing space. These have been (1) establishing a major role for the Center in overall management of launch services for intermediate and large launch vehicles, and (2) establishing the first launch services contract for the National Oceanic and Atmospheric Administration (NOAA) geostationary operational environmental satellites (GOES) missions, which helped to usher in the new era of space commercialization

NASA Lewis' roles and responsibilities for intermediate and large ELV's.—The Project Office has used the experience and expertise obtained over the last several decades to capture a significant role in the new ELV Mixed Fleet Program established by NASA Headquarters. Following a series of meetings with Headquarter's senior management, Lewis was assigned management responsibility for the intermediate and large ELV's—Atlas-Centaur, Titan III, and Titan IV. Lewis has developed, and is in the process of executing, a management and procurement strategy that furthers responsible commercialization of space while ensuring that our national needs are fulfilled. The first attempt at interpreting the new guidelines was the procurement of launch services for the NOAA GOES missions.

GOES launch services procurement—pathfinder for NASA's mixed fleet.—On May 20, 1988, the complex procurement of the first commercial launch services for Government satellites was completed with the signing of a $200 million contract with General Dynamics for the delivery to orbit of a series of weather satellites. Lewis, acting as an agent for NOAA, conducted the procurement and will manage the firm fixed-price contract. The contract provides for total ELV launch services for three geostationary operational environmental satellites (GOES) from 1990 through 1992. Options for launch services on two additional satellites are also included in the contract. The GOES satellite system plays a critical role in predicting and monitoring severe weather so as to provide early warning and thereby minimize damage caused by storms.

Lewis contact: John W. Gibb, (216) 433-6192
Headquarters program office: OSF

University Space Engineering Research Centers Established for Space Propulsion R&T

In the summer of 1988, NASA's Office of Aeronautics and Space Technology (OAST) established nine university-based Space Engineering Research Centers as a result of the August 1987 program notice. They support NASA's goal of broadening the nation's engineering capability to meet the critical needs of the civilian space program. The centers will conduct focused research in one or more of the traditional space engineering disciplines and in cross-discipline combinations as well as enhance engineering education. The overall program is managed from OAST under the direction of a program manager. A steering committee made up of NASA Headquarter's and center personnel will provide policy direction. A team of co-monitors for each university center will ensure the timely flow of information and technology between the centers and NASA programs and foster collaborative arrangements such as the exchange of personnel and the use of NASA facilities. The nine centers were selected from 115 proposals. Another competitive round is planned to expand the participation and the program over the next few years to about 20 university centers.

The Space Propulsion Technology Division at NASA Lewis is currently associated with three university centers: the Health Monitoring Technology Center for Space Propulsion Systems at the University of Cincinnati; the Center for the Utilization of Local Planetary Resources at the University of Arizona; and the Center for Space Propulsion Engineering at Pennsylvania State University.

Health Monitoring Technology Center for Space Propulsion Systems.—The primary purpose of this center will be to conduct basic analytical and experimental research into space propulsion systems capable of safely and reliably performing repeated missions. This requires an on-line means of diagnosing component life and of predicting imminent deterioration and its effect on performance degradation and reliability.

Center for the Utilization of Local Planetary Resources.—This center's major objective is instruction and research dedicated to providing space-derived materials, including propellants, structural metals, and shielding. Simulated Moon and Mars soil samples will be produced, characterized chemically and physically, and used to develop in-situ processes and equipment for utilizing these materials.

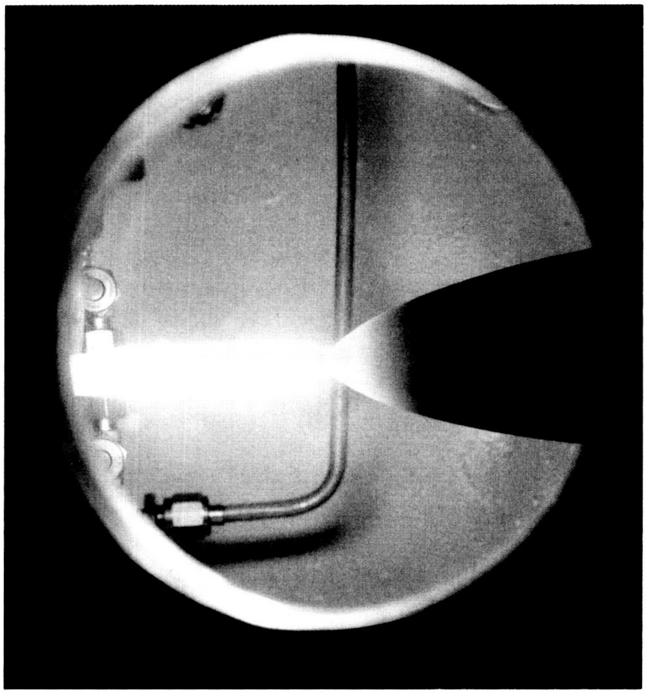
Center for Space Propulsion Engineering.—This center's areas of focus include three propulsion categories—chemical, electric and nuclear, and advanced concepts—and two supporting technologies—diagnostics and materials compatibility and reliability. Research projects will include studies in combustion instability, metallized slurry propellants, and arcjets and magnetoplasmadynamic devices. Advanced concepts may involve solar, laser, and microwave, as well as metastables, metallic hydrogen, and chemically bound and maximum-ionicity exited states.

Lewis contact: Dr. Larry P. Cooper, (216) 433-8089
Headquarters program office: OAST

Materials

Demonstration of High-Temperature Rocket Life

Wall temperatures in small chemical rockets are typically maintained at or below the material operating temperature by using fuel film coolant. For small thrusters the coolant level reaches 30 to 40 percent of the total fuel. The best materials currently available for these thrusters are silicide-based protective coatings on a niobium substrate. Their upper temperature limit is approximately 1400 °C. Because of the difference in thermal expansion between the materials, repeated temperature cycling cracks the coating and ultimately destroys the base material.



5-lbf high-temperature flight thruster

An 800 deg C increase in the operating temperature of thruster materials has been demonstrated in over 15 hr of thruster operation at temperatures between 2000 and 2260 °C. The thrust chamber was fabricated from the refractory material rhenium. Because this material exhibits notoriously poor resistance to oxidation in the temperature range where its strength characteristics are vitally needed, a newly developed high-temperature protective coating of iridium was chemically vapor deposited on the rhenium. The demonstration was conducted with a small (22 N) thruster fired with N_2O_4/MMH propellants.

This iridium-coated rhenium chamber technology makes possible approximately a 20-sec increase in the specific impulse of 22-N thrusters. Significantly less propellant mass is thus required for orbit insertion and orbit control of most satellites. Either the satellite payload can be larger or the life of the satellite can be longer—both of which significantly affect satellite system operation.

Lewis contact: Steven J. Schneider, (216) 433-2445
Headquarters program office: OAST

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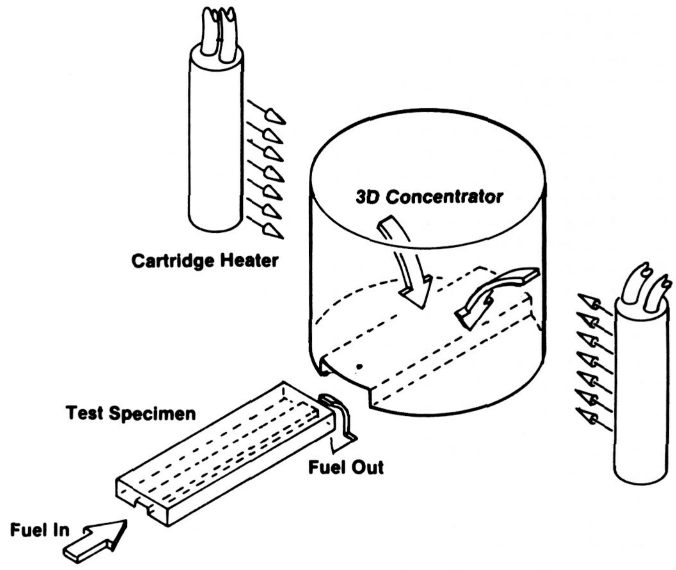
Compatibility of Hydrocarbon Fuels and Combustion Chamber Liner Materials

Geometric concentration of energy as an alternative to obmically beated test specimens



Consideration is being given to developing a long-life booster engine for the Advanced Launch System that will use liquid oxygen and hydrocarbon fuels as propellants. Three fuels are currently under consideration: RP–1, propane, and methane. Since the booster engine would be operated at high chamber pressures, the combustion chamber liner would have to be fabricated from copper or copper-base alloys in order to transfer the high heat load through the chamber wall to the fuel coolant. However, in prior research conducted to determine the cooling capabilities of hydrocarbon fuels, the electrically heated copper tubes severely corroded. Although ohmic heating of fuel-cooled tubes has been an accepted method of conducting coolant-side heat transfer experiments, there has been concern that the high electrical current required to produce simulated booster engine heat flux levels contributed to the corrosion mechanism. Since the potential for corrosive interaction between copper and the candidate hydrocarbon fuels could have an enormous effect on booster engine life, it was imperative that further research be conducted to determine their compatibility.

Aerojet TechSystems Company was awarded a contract by NASA Lewis with the objectives of (1) defining the corrosive interaction process between hydrocarbon fuels and copper combustion chamber liner materials, and (2) developing and demonstrating protective measures against this corrosive process.

Aerojet designed and built a unique dynamic test apparatus capable of realistically simulating booster engine cooling channel conditions without direct ohmic heating. A large copper block is heated by 10 electrically insulated cartridge heaters embedded in the block. The heat input into the block is transferred by conduction through a copper test specimen. The heat is then withdrawn by fuel flowing through a 0.020-in.-square cooling channel milled in the bottom of each specimen. Coolant-side heat fluxes of 53 Btu/in.^{2} sec can be obtained with this apparatus.

Dynamic tests were conducted with four hydrocarbon fuels—military specification RP–1, *n*-dodecane (as a high-purity simulant for RP–1), methane, and propane—and three copper chamber materials—oxygen-free, high-conductivity (OFHC) copper, NASA-Z (3Ag–0.5Zr), and Amzirc (0.15 Zr). Very high-purity fuels were used in the initial tests, and sulfur-containing compounds were added in subsequent tests. With no sulfur present the copper materials and the fuels did not react. With sulfur added, however, the copper corroded severely. Even sulfur concentrations of 1 ppm showed some reaction. The results of this program will be instrumental in making the fuel selection for a new booster engine.

Lewis contact: Richard J. Quentmeyer, (216) 433-2462
Headquarters program office: OAST

Structural Mechanics

Probabilistic Analysis of Space Shuttle Main Engine Blade Structural Response

A unique capability has been developed at NASA Lewis to assess the structural performance of space shuttle main engine components. The capability incorporates finite-element analysis together with probability methods and a statistical concept for performing numerical experiments known as factorial design. It provides quantitative information relative to the effects of design variable uncertainty on structural response.

As an example, the structural performance of a high-pressure turbopump blade has been evaluated in terms of common response variables (displacement, natural frequency, and stress) and their probability distributions due to combined geometry and material design variable uncertainty. The distributions indicate the range in magnitude and probability of occurrence for a particular response variable. A wide range of predicted structural response, such as shown for maximum stress variation, implies that small (naturally occurring) uncertainties in geometry and material properties can cause a large uncertainty in structural response. A degree of "risk" of unacceptable performance necessarily accompanies this uncertainty.

Traditional design practice based on deterministic methods provides no means to address the issue of risk associated with the uncertainty of an engineering design. Indeed, the concept of "safety factor" in deterministic design is an attempt to eliminate risk. Reducing risk increases not only safety or reliability but also cost. Probabilistic analysis methodology provides essential information for quantifying risk and making design decisions commensurate with safety requirements.

Bibliography

Chamis, Christos C.: Probabilistic Structural Analysis Methods for Space Propulsion System Components. Prepared for 3rd Space System Technology Conference, AIAA, San Diego, CA, June 9–12, 1986. NASA TM-88861, 1986.

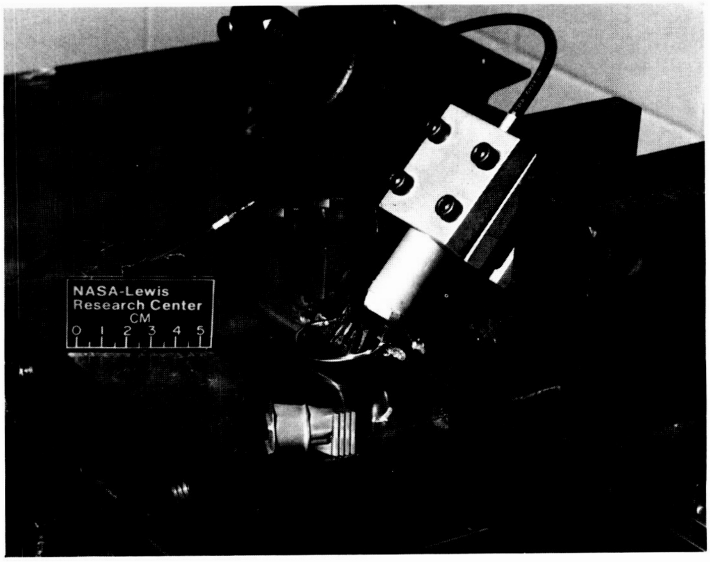
Lewis contacts: Dr. Christos C. Chamis, (216) 433-3252; Dale A. Hopkins, (216) 433-3260
Headquarters program office: OAST

High-Pressure Turbine Blade Damper Optimization

The first-stage turbine blades on the space shuttle main engine (SSME) high-pressure oxygen pump have experienced cracking problems because of excessive vibration. A solution is to attenuate blade vibration by incorporating well-designed friction dampers. In a cooperative effort between NASA Lewis and Carnegie-Mellon University, recently developed friction damper technology was applied to the SSME high-pressure oxygen turbopump. The major emphasis was on the contractor design known as the two-piece damper. Damping occurs at the friction interface between the top half of the damper and the underside of the platforms of the adjacent blades. The lower half of the damper is an air seal to retard airflow in the volume between blade necks.

A bench test apparatus was developed for conducting an extensive set of experiments on the two-piece damper. The bench

test apparatus was successful. The normal load was applied through a fishhook-pulley-weights system. The weights were varied from 0.25 to 70 lb. The blade support was tuned to simulate blade natural frequencies at pump operating temperatures and speeds (~9.5 kHz for the edgewise bending mode). The excitation system consisted of an electromagnet and a small chip of transformer iron mounted on the blade. Blade response, measured with a miniature accelerometer, was up to 700g tip acceleration, 0.1-mil tip displacement, and 1700-psi stress at the crack location.



High-pressure-turbine-blade bench test apparatus

Analytical models were fit to the experimental data and used to extrapolate the results to pump operating conditions. These extrapolations showed that the best thickness for the two-piece damper is 0.047 in. and that the performance could be improved by reducing width by 15 percent. However, the damper was found to be working in the microslip regime (no gross slipping). The resulting reduction in stress was predicted to be approximately 3 to 1.

Whirligig testing at the contractor showed that tip clearance is the controlling parameter in blade vibration. In addition, testing of a tip diameter showed excellent performance characteristics.

Lewis contacts: Dr. Robert E. Kielb, (216) 433-6049; Erwin H. Meyn, (216) 433-6026
Headquarters program office: OAST

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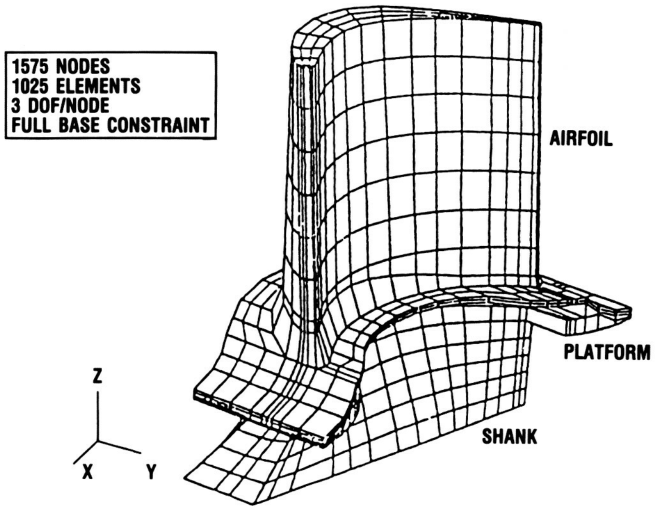
Dynamics of Space Shuttle Main Engine Single-Crystal Turbine Blade



MSC/NASTRAN finite-element model

Many concerns surround the current blades for the space shuttle main engine first-stage, high-pressure fuel turbopump (HPFTP). The blades, which are made of directionally solidified (DS) material, have a design life goal of 55 launches. However, they have been serviceable for only two to five launches. The blade life has been primarily influenced by fatigue cracking problems. One way to improve blade life is to make the blades of single-crystal (SC) material. Past experience and current applications with commercial and military aviation have shown the feasibility of using SC material.

Research was conducted at NASA Lewis to predict the SC blade natural frequencies and to find possible critical engine-order excitations. Both the first- and second-stage drive turbine blades of the HPFTP were examined. The effort was both experimental and analytical. Experiments were used to validate the analytical procedures. Bench experiments for five SC blades at different crystal orientations were conducted to determine their nonrotating natural frequencies and mode shapes. These results were compared with the analytical results to confirm the validity of the analytical (MSC/NASTRAN) model. The analytical effort examined the blades' dynamic characteristics with respect to crystal orientation under typical operating conditions. Additional investigations attempted to determine the crystal orientation that would most effectively avoid critical engine-order excitations.

From a dynamics viewpoint the SC blade is an improvement over the DS blade. No new engine-order interferences were introduced with the material substitution. The SC blade at nominal orientations was found to be better than the DS blade because the fourth-mode interference was eliminated. The engine-order interferences within the SC blade's first three modes can be minimized by changing the crystal orientation. However, for any orientation the third mode interference will always exist.

Lewis contact: Larry A. Moss, (216) 433–6033
Headquarters program office: OAST

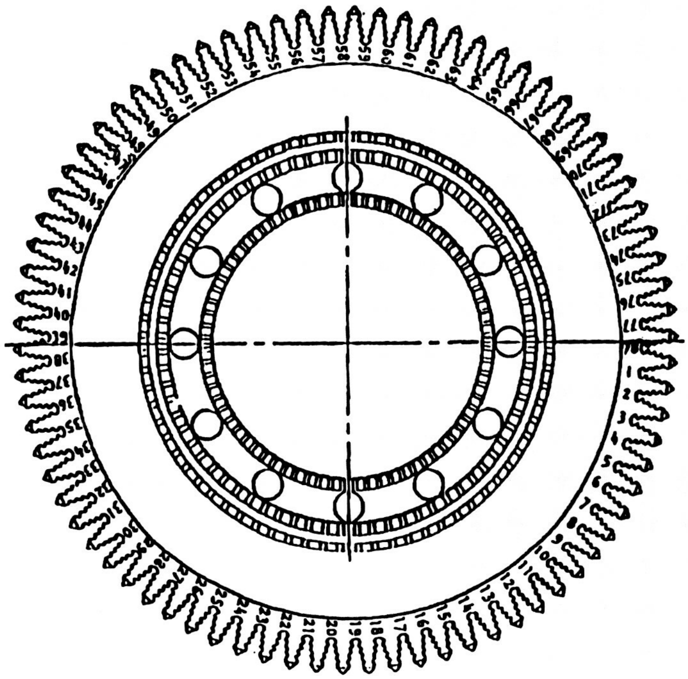
Life Prediction

Reliability of Space Shuttle Main Engine Liquid-Oxygen Turbopump

The reliability of the space shuttle main engine (SSME) liquid-oxygen turbopump was analyzed at NASA Lewis. This analysis was part of a much broader examination of the probability that a space shuttle mission would fail. Three pump components were identified as critical to turbopump reliability: the turbine disks, the turbine blades, and the rolling-element bearings.

The analysis for the turbine disks was applied to a single potential failure location—the root of a blade fir tree attachment slot at the rim of the first-stage, high-pressure oxidizer turbopump. This location has been judged on a deterministic basis as having the most severe stress-strain-temperature history leading to the shortest low-cycle fatigue life of all locations on this disk or on any of the three other disks in an SSME powerhead. Only intended mission loadings were considered in the analysis (i.e., loadings caused by the failure of some other component that could affect the disk loading were not considered).

The probability of failure of first-stage blades in the SSME high-pressure oxidizer turbopump was evaluated by performing the following analysis: (1) a Monte Carlo simulation using a strength degradation equation, (2) analysis of the relevant data provided by Rocketdyne, and (3) the probability of failure obtained in terms of the cumulative probability distribution.



First-stage turbine disk of SSME liquid-oxygen turbopump

The mechanism that limits bearing operation in the turbopump is bearing wear. The initiation and progression of bearing wear is a random process that cannot be predicted with reasonable engineering or scientific certainty. Bearing wear can be caused by rolling-element fatigue. Rolling-element fatigue can be predicted with reasonable engineering certainty by using probabilistic methods. Hence rolling-element fatigue can be used as a criterion for predicting the initiation of bearing wear. It was assumed that in a worst-case scenario rolling-element fatigue would occur on the first revolution of a bearing in the turbopump. Total allowable bearing wear would be 0.002 in., resulting in 0.004 in. of shaft travel and causing a rub of the turbine blade.

For the turbine disk the probability of failure for three engines was 4.5×10^{-10}. For one set of turbine blades on the first-stage turbine for combined thermal and mechanical loading, the probability of failure was 11×10^{-6}. For the bearings a rub owing to bearing wear will occur at the turbine housing interface with at least one turbopump in 1 out of 15 missions. Experience at Marshall Space Flight Center has shown, however, that where a rub has occurred, no secondary damage was experienced.

Lewis contacts: Erwin V. Zaretsky, (216) 433-3241; Dr. Gary R. Halford, (216) 433-3265; Dr. Christos C. Chamis, (216) 433-3252
Headquarters program office: OAST

Arcjet Life Verification

Arcjet thrusters employ an arc to heat a propellant such as the decomposition products of hydrazine to produce thrust. Performance measurements on low-power, direct-current arcjet thrusters have shown that specific impulse levels in the 450-sec range can reasonably be expected at the 1.2-kW power level. This represents a 50-percent increase over auxiliary propulsion systems currently in use. NASA Lewis is investigating these thruster systems for application to north-south stationkeeping on communications satellites. Over the past 3 years, problems caused by uncontrolled starting transients and steady-state instabilities have been solved with a combination of optimized propellant flow field and thruster geometry and improved power electronics.

Arcjet thruster on test stand

NASA Lewis performed an automated cyclic life test to demonstrate the reliability and endurance necessary for a stationkeeping mission. A hydrogen-nitrogen propellant mixture was used to simulate the decomposition products of hydrazine, and the power level was nominally 1.2 kW, the level expected to be available for arcjet operation in space. Over 1000 hr of operation were accumulated in 4-hr, 50-percent cycles to approximate a stationkeeping scenario. A burn-in period was found to be necessary during which the cathode tip recessed to nearly a steady-state shape. Afterwards the arcjet operated reliably throughout the test. The steady-state operating voltage increased by 6 V over the first 300 hr of testing and then by only 3 V over the final 700 hr. Thruster performance measurements taken before, during, and after the test verified that the thruster operated consistently throughout the test at a specific impulse of 450 to 460 sec. Post-test component evaluation showed limited erosion on both the cathode and the anode. Other thruster components, including the graphite seals, appeared to be undamaged. No life-limiting mechanism was observed, and it is estimated that the thruster testing could have been greatly extended had more hours of operation been necessary.

Lewis contact: Frank M. Curran, (216) 433–2408
Headquarters program office: OAST

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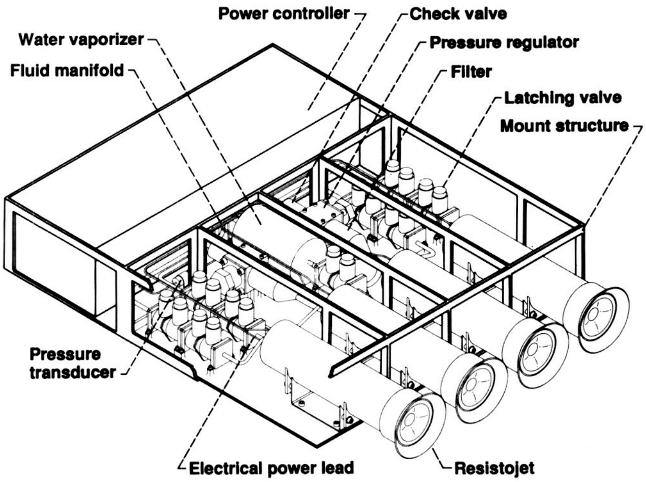
System Studies

Conceptual Design Study of Space Station Resistojet

A conceptual design study of the space station resistojet system was conducted in-house at NASA Lewis and through a contract with Rocketdyne-Technion. It was completed in early fiscal 1988. The design requirements were directed toward long life, simplicity, and commonality with other space station components.

The functions of the resistojet propulsion system are to dispose of waste gases and to provide impulse for stationkeeping. Cost savings can be realized by using excess fluids in the resistojets. Propellant resupply for altitude maintenance is eliminated or reduced, and the logistics problems and costs associated with disposing of excess fluids are reduced. Potential resistojet propellants include inert gases, water vapor, carbon dioxide, oxygen, cabin air, methane, and hydrogen. Estimates of waste gases produced range from 2000 to 5000 kg/yr. Heating and exhausting these gases through a resistojet can provide a significant proportion of the impulse needed for stationkeeping.

A conceptual design has two redundant resistojet orbital replacement units located on a truss that extends beyond the modules. Each unit consists of four 500-W multipropellant resistojets, fluid components downstream of the waste fluid storage subsystem, a power controller, structure, and micrometeoroid shielding. The fluid components include latch valves, a water vaporizer, two



Resistojet module layout

pressure regulators or flow control valves, filters, check valves, fluid tubing, and interface coupling. Separate fluid components are provided for oxidizing fluids, reducing fluids, and water.

A high-temperature mode offers relatively high specific impulse with long life. A low-temperature mode can propulsively dispose of mixtures that contain oxygen or hydrocarbons without reducing thruster life or generating particulates in the plume. A low duty cycle and a plume that is confined to a small aft region minimize the effects on the users. Simple interfaces with other space station systems facilitate integration.

Bibliography

Tacina, Robert R.: Conceptual Design and Integration of a Space Station Resistojet Propulsion Assembly. NASA TM–89847, 1987.

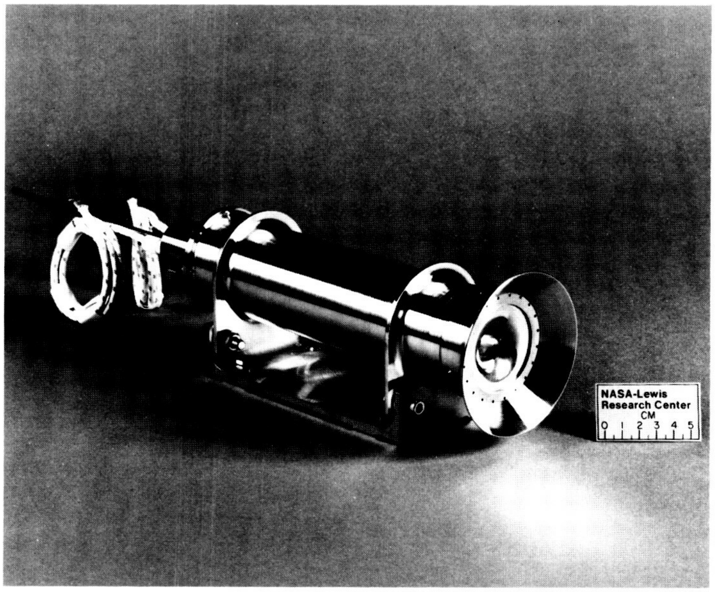
Lewis contact: Robert R. Tacina, (216) 433–3588
Headquarters program office: OSS

Life Testing of Space Station Resistojet Thrusters

A requirement of the space station propulsion system is to maintain orbital altitude. A requirement of the space station fluid management system is to dispose of the waste gases generated by the environmental control and life support system and the scientific experiments. The space station resistojet thruster satisfies both of these requirements.

The resistojet thruster is basically a device that heats a fluid and exhausts it through a nozzle to produce thrust. Resistance heating (hence the name) is the mechanism by which energy is added to the fluid. On the space station the fluid will generally be waste gases. This fluid is then expanded through a nozzle, producing thrust as it accelerates away from the station to prevent the contamination of the surrounding environment.

As a result of a contract that ended this year, Rocketdyne-Technion provided five resistojet thrusters to NASA Lewis for in-house testing. Because the flow rates of waste gas through the thruster are low and large quantities of waste gases will be generated by the space station, each thruster must last a long time. To determine how long, we placed one on life test as soon as possible. As of July 1988 this thruster had accumulated over 7000 hours of successful operation at 1200 °C and 97 thermal cycles between 27 and 1200 °C. This testing has been done in a vacuum chamber with some attempt to simulate zero gravity by inverting the thruster occasionally. By surpassing the 4000-hr mark this thruster now holds the record for operational lifetime for a resistojet.



Resistojet test article

Bibliography

Finden, L.E.: Space Station Resistojet System Requirements and Interface Definition Study. NASA CR-180832, 1987.

Lewis contact: Rodger R. Slutz, (216) 433-6299
Headquarters program office: OSS

Advanced Space Analysis Office Assists NASA Headquarters

The Advanced Space Analysis Office (ASAO) has conducted analyses and studies for several NASA Headquarters offices in areas of traditional Lewis disciplinary strengths such as power, propulsion, fluid management, and communications.

The ASAO has been a major contributor this year to the Agency's planning of bold initiatives involving exploration of the solar system. Working under the direction of the Office of Exploration as the special assessment agent in the areas of power and propulsion, ASAO has conducted analyses and tradeoff studies that are helping to define the NASA missions of the next century. Studies have been completed and reports written in several areas with significant contributions from other Lewis technology organizations. Some of these are a conceptual design of a nuclear power system for a lunar base, a workshop on and study of the application of nuclear thermal rockets for manned missions to Mars, and a workshop assessing the feasibility of mining helium-3 on the Moon for terrestrial fusion applications.

The Center's extensive launch vehicle experience was used to conduct several studies for the Office of Space Flight. The feasibility of using a shuttle type of Centaur as an upper stage for the unmanned shuttle-C heavy-lift launch vehicle was and continues to be investigated jointly by ASAO and the Launch Vehicle Projects Office. Mission analyses have been conducted for a planned Titan launch vehicle backup for the Galileo, Ulysses, and Magellan missions.

At the request of the Office of Aeronautics and Space Technology (OAST) a workshop was hosted by ASAO at which scientists and engineers from NASA and industry met to assess the critical technologies required for developing an orbiting cryogenic fuels depot. A broad spectrum of technologies in cryogenic fluids management, materials and structures, space operations, and safety was identified, and their states of maturity and criticality were assessed. All of the data developed at this workshop were entered into a data base and a "depot technology roadmap" was delivered to OAST for use in their strategic planning.

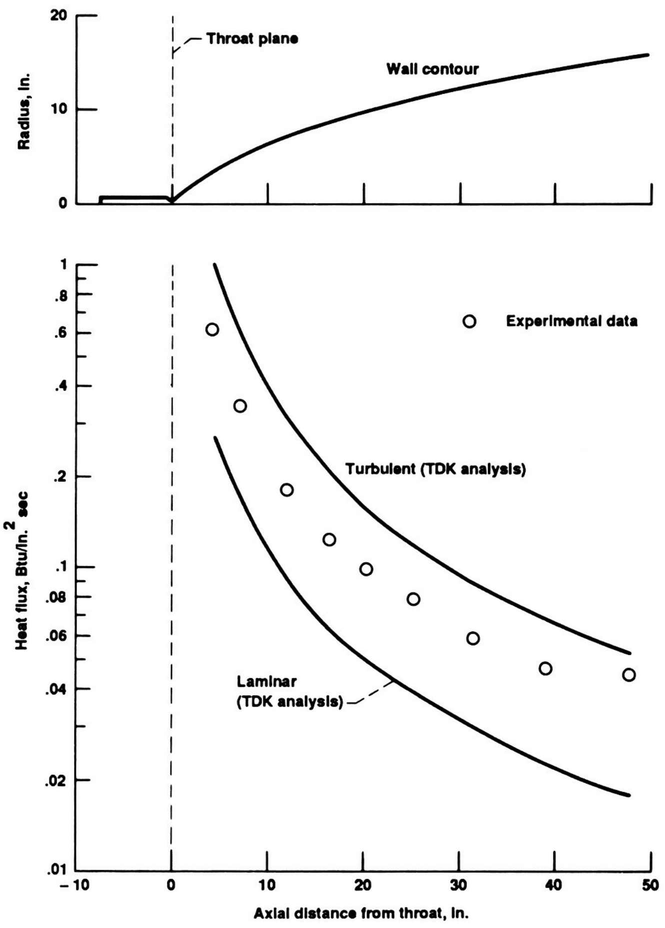
Finally, an important role for the Center in the Mars Rover and Sample Return Program of the Office of Space Science and Applications was secured this year in which Lewis provides support to the NASA Johnson Space Center and the Jet Propulsion Laboratory in launch vehicles, power, and communications.

Lewis contact: Dr. Robert M. Stubbs, (216) 433-6303

Heat Transfer

Boundary Layer Development in a 1030:1 Area Ratio Rocket Nozzle

The concept of a high-performance, compact space engine is currently being evaluated by the aerospace community as part of NASA's Chemical Transfer Vehicle Technology Development Program. This concept includes the use of large-area-ratio nozzles. The Lewis 1030:1 rocket nozzle is the first nozzle of this size to be tested and is to provide a performance data base for large-area-ratio nozzles. Because of the large area ratio the boundary layer drag is expected to be significant. The question is whether the benefit of increased performance, gained by using large-area-ratio nozzles, will outweigh the problem of increased boundary layer drag. Therefore it is important to understand the boundary layer development within the 1030:1 nozzle during testing in terms of the amount of drag produced and its effect on the measured performance.



Experimental and predicted nozzle wall heat flux for 1030:1 nozzle at chamber pressure of 1004 psia

NASA Lewis conducted a study to determine the rocket engine chamber pressure at which the boundary layer flow in the 1030:1 nozzle can be considered to be laminar and the pressure at which it will be turbulent. Tests were performed on the nozzle at chamber pressures from 350 to 1000 psia. For these conditions the throat diameter Reynolds number varied from 300,000 to 1 million. The propellants used were gaseous hydrogen and gaseous oxygen. Thrust measurements and nozzle outer-wall temperature measurements were taken during the 3-sec test runs.

Comparing the experimental heat transfer and thrust data with the corresponding predictions from the two-dimensional kinetics (TDK) nozzle analysis program indicated laminar flow in the nozzle at a throat diameter Reynolds number of 320,000, or a chamber pressure of 360 psia. Comparing experimental and predicted heat transfer data indicated transitional flow up to and including a chamber pressure of 1000 psia. Predicted values of the axisymmetric acceleration parameter within the nozzle were consistent with these results. From an extrapolation of the heat transfer data and predicted distributions of the axisymmetric acceleration parameter, transitional flow was predicted up to a throat diameter Reynolds number of 2.2 million, or a chamber pressure of 2600 psia. Above this pressure fully developed turbulent flow was predicted. Recommendations were made for further tests at chamber pressures from 1500 to 3000 psia in order to obtain heat flux and performance data to support the analysis.

Lewis contact: Tamara A. Smith, (216) 433–2467
Headquarters program office: OAST

Performance and Heat Transfer of 3000-lb-Thrust Annular Thrust Chamber

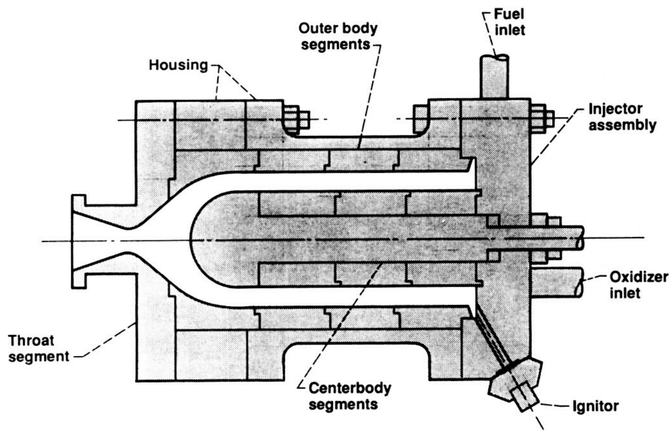
As a part of NASA's Chemical Transfer Vehicle Technology Development Program, Aerojet TechSystems has been researching a new engine design based on the dual-expander engine cycle. This design deviates from the conventional expander engine cycle by using oxygen as the turbine working fluid in the oxygen turbopump. This reduces the demands on the hydrogen circuit and allows the turbopump to be designed without interpropellant seals or mechanical gear train connections.

Aerojet's initial concept for this engine was a 3000-lb-thrust design that ran the oxygen propellant through a cylindrical centerbody placed in the combustion chamber in order to acquire sufficient thermal energy to power the oxygen turbopump. NASA Lewis provided heat transfer and performance data to support the design of this thrust chamber concept.

The test program was divided into two parts: low-pressure tests (chamber pressures from 100 to 600 psia) and high-pressure tests (chamber pressures from 500 to 2000 psia). Aerojet designed and instrumented a copper heat-sink combustion chamber and centerbody for use in measuring the axial and circumferential heat transfer. The combustion chamber was designed with an internal diameter of 5.62 in. and a length of 10 in. The centerbody was designed with a diameter of 4 in. and a length of 12.5 in. A copper heat-sink throat was used for the low-pressure tests. For the high-pressure tests a hydrogen-cooled throat section was designed with 0.01-in.-wide (mini-channel) coolant channels. A high-performance annular injector was designed and built with 72 premixing "I" triplet elements.

Tests were run at chamber presures of 200, 400, 500, 600, 1000, and 2000 psia over a mixture ratio range of 3 to 8. Centerbody and combustion chamber heat flux profiles were obtained. Performance of the annular injector and the hydrogen-cooled "mini-channel" design was demonstrated. Results from this test program include heat flux profiles that can be used in future engine designs, performance data for the annular injector that will be used to modify that injector design, and techniques for plating nickel-cobalt developed while fabricating the cooled throat, which resulted in a lightweight, thin (0.018 in.) closeout.

Lewis contact: Tamara A. Smith, (216) 433-2467
Headquarters program office: OAST



Annular heat-sink thrust chamber assembly

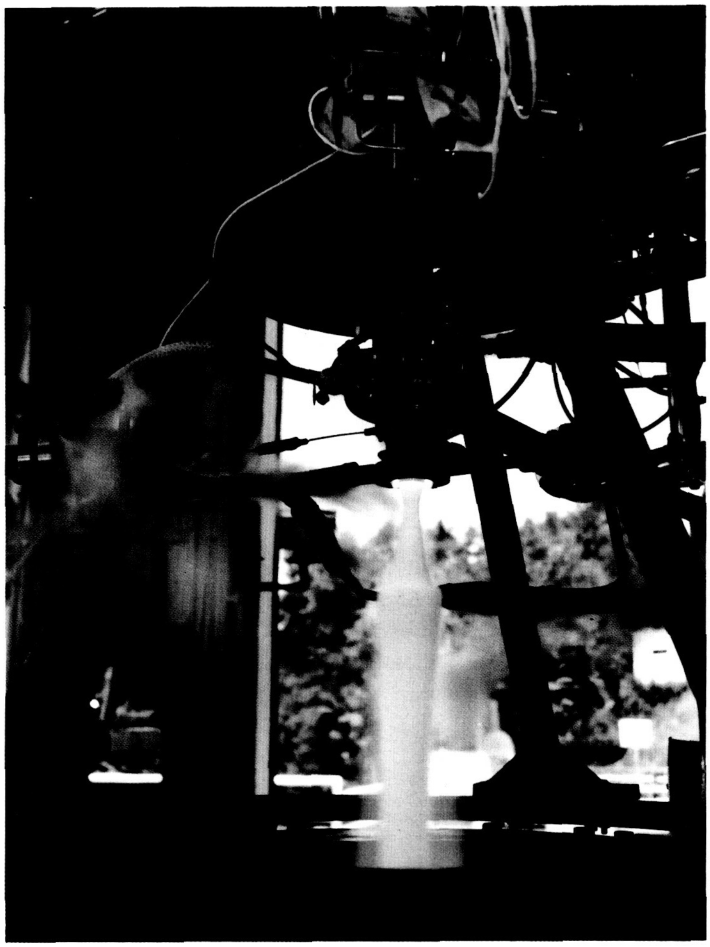
Liquid-Oxygen Cooling of Rocket Engines

Future launch vehicles will require very high-chamber-pressure, hydrocarbon-fueled rocket booster engines. Typically the fuel in a rocket engine is used to regeneratively cool the engine's combustion chamber. However, an inherent disadvantage of the heavier hydrocarbon fuels such as RP–1 (kerosene) is their tendency to decompose in the cooling channels. The resulting carbon deposit buildup in the channels reduces their cooling capability. Furthermore the trace impurities in the fuel corrode the copper walls by chemical attack. Therefore the oxidizer (liquid oxygen) must be considered as the coolant for an advanced liquid oxygen–hydrocarbon engine.

NASA Lewis began experimental testing this year to evaluate the cooling characteristics of liquid oxygen with liquid oxygen and RP–1 as propellants and to observe the effects of internal liquid-oxygen leaks on the structural integrity of the combustor. Further research into the effect of liquid-oxygen leaks from the cooling channels to the combustion area between the throat and the injector will be necessary to determine the safety of oxygen as a coolant.

Although liquid-oxygen cooling had previously been incorporated in test programs, this research increased the total testing experience with liquid-oxygen cooling and investigated the results of small amounts of oxygen flowing into the thrust chamber along the sides.

Preliminary testing has shown that liquid oxygen cools successfully over an extended period of time.



Liquid-oxygen-cooled engine during testing

For a given flow rate the heat flux was 25 to 30 percent more than predicted. The next phase of the program will include testing chambers with liquid-oxygen leaks at various axial locations. The chambers will be tested for structural integrity and performance. The temperature of the chamber wall will be measured directly downstream from the leaks to determine if the leaking liquid-oxygen film cools the side of the engine or if it reacts with the combustion gases or carbon deposits on the wall to heat up the chamber wall. The next phase of testing is scheduled for early fiscal 1989.

Bibliography

Armstrong, E.S.: Test Program to Provide Confidence in Liquid Oxygen Cooling of Hydrocarbon Fueled Rocket Thrust Chambers. The 1986 JANNAF Propulsion Meeting, Vol. 1, K.L. Strange and D.S. Eggleston, eds., CPIA–PUBL–455–VOL–1, Chemical Propulsion Information Agency, 1986, pp. 361–367. (NASA TM–88816.)

Price, H.G.: Cooling of High-Pressure Rocket Thrust Chambers With Liquid Oxygen. J. Spacecraft Rockets, vol. 18, no. 4, July-Aug. 1981, pp. 338–343.

Price, H.G.; and Masters, P.A.: Liquid Oxygen Cooling of High Pressure LOX/Hydrocarbon Rocket Thrust Chambers, NASA TM–88805, 1986.

Lewis contact: Elizabeth S. Armstrong, (216) 433–2462
Headquarters program office: OAST

Preliminary Design of 7500-lb-Thrust Engine

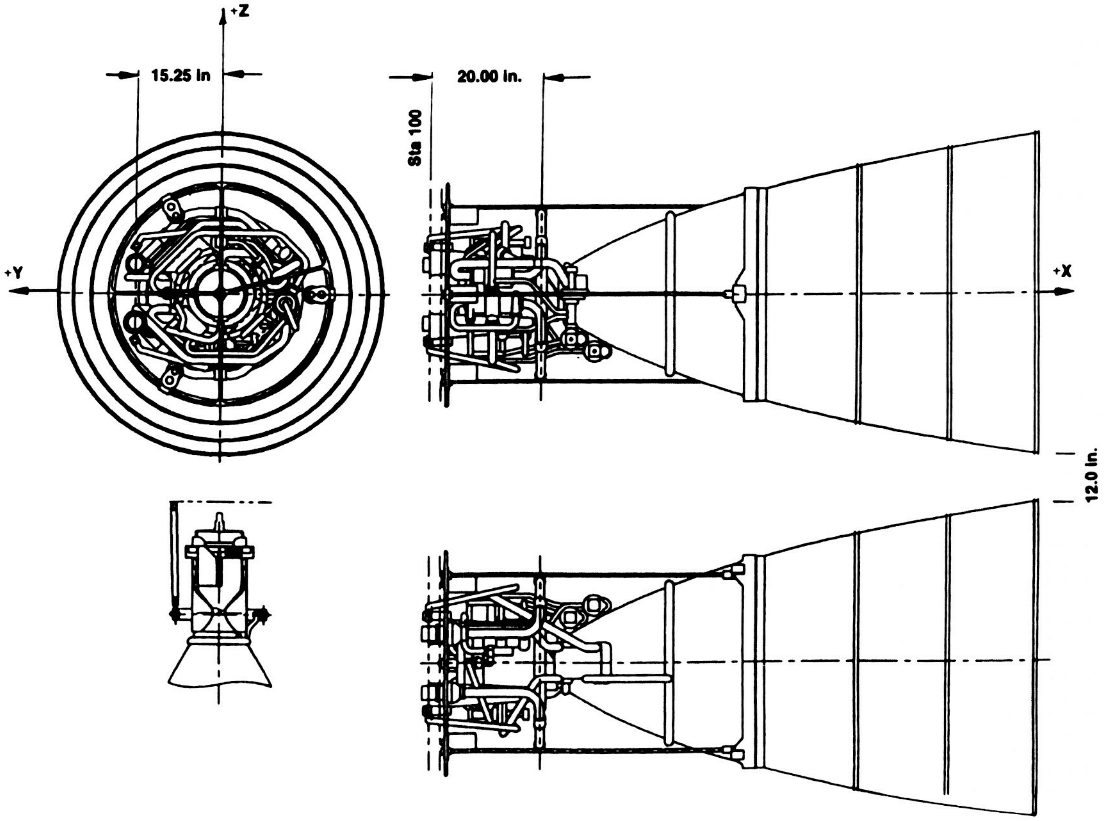
Two preliminary orbit transfer vehicle (OTV) engine designs, with different expander cycles, have been completed. Preliminary descriptions and operating characteristics are now available. This provides a firm foundation for the next step in the engine technology program.

The Orbit Transfer Vehicle Rocket Engine Technology Program was established by NASA Lewis in 1983 to develop the advanced technology required for the OTV engine. The objective of the present phase was to verify advanced component technology to help shorten the full-scale development of the advanced engine anticipated in the middle to late 1990's and reduce its cost. The overall plan was to integrate advanced technology components, verified in other tasks of this program, into an advanced engine design. It is this integrated design, as a separate task, that has been completed and is reported on herein.

Two parallel task orders were let, one with Rocketdyne, and the other with Aerojet. Each contractor produced a preliminary design of a 7500-lb-thrust OTV engine. Included in the design were vehicle-derived propulsion system requirements, along with experimental data generated in the thrust chamber and turbomachinery studies. The resultant engine designs are expander cycle, hydrogen-oxygen fueled, space based, human rated, and 10:1 throttleable.

Both designs feature extended surface area in the combustor to allow more enthalpy extraction for the turbopumps. The Rocketdyne design has ribbed and finned coolant passages. The Aerojet design has cooled baffles in the combustor. Turbopumps have been designed and the total cycle balances have been determined.

Lewis contact: Albert J. Pavli, (216) 433–2470
Headquarters program office: OAST

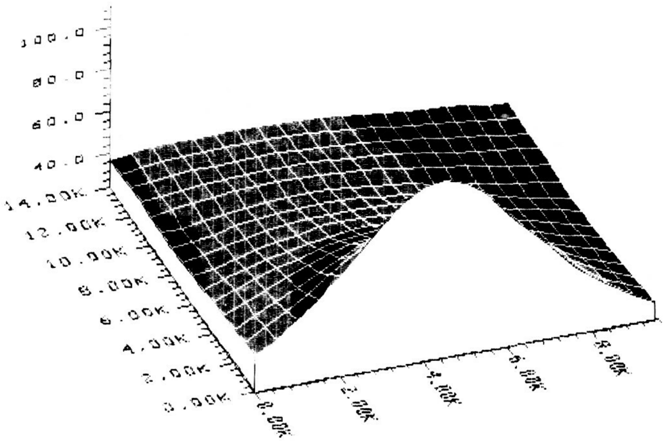


Aerojet design for 7500-lb-thrust engine

Instrumentation

Heterodyne Holographic Interferometry for Leak Detection in Propulsion Systems

It is desirable to be able to detect, locate, and measure helium leaks as small as 0.1 std in.^{3}/min in space propulsion components. It is also desirable to be able to detect these small leaks in the presence of larger leaks. Several holographic techniques have the necessary sensitivity and dynamic range for this application.



Map of 0.8-std in.^{3}/min leak in horizontal tube

NASA Lewis has constructed a laboratory in which to perform research on a variety of optical measurement techniques, including optical heterodyning. Optical heterodyning permits a direct mapping of the optical phase change (interference phases) between no-leak and leak conditions of a component. These two conditions can be recorded in the field by using double-exposure holography. The result is a leak-induced interference fringe pattern. The laboratory setup then performs automated, microcomputer-controlled mapping and display of the interference phase of this pattern. Additional useful properties of optical heterodyning are a sensitivity increase of 10 to 100 over conventional holographic interferometry and the ability to determine the spatial location of a leak.

Leak detection has been demonstrated for a variety of conditions. The leak detection range extends from less than 0.1 std in.^{3}/min to 4000 std in.^{3}/min. Simultaneous leaks ranging from 0.8 to 80 std in.^{3}/min were recorded and mapped with the same hologram. This work was part of an ongoing effort to use electronic and fiber optic holographic interferometry for optical inspection of space propulsion components.

Lewis contact: Dr. Arthur J. Decker, (216) 433-3639
Headquarters program office: OAST

Nationally Recognized Cryopumping System Operational in EPL's Tank 5

The Electric Power Laboratory at NASA Lewis houses both a 15-ft- and a 25-ft-diameter space environment chamber. Tank 5, the 15-ft-diameter chamber, is 63 ft long and was designed primarily for space simulation testing of spacecraft and electrothermal thrusters. The maximum pumping speeds for the system as originally designed were 250,000 and 660,000 liters/sec for nitrogen and hydrogen, respectively, at vacuum levels of 10^{-4} torr.

Advanced propulsion flow requirements exceed these facility capabilities by as much as a factor of 10. In order to provide the needed pumping speed, a liquid-nitrogen-shielded, helium-cooled cryopanel system has been installed in Tank 5. A helium liquefier/refrigerator provides either cold helium gas (15 K) or liquid helium for cooling the helium surfaces of the cryopanel. These cooled surfaces then condense the propellant gases, providing space environment vacuum conditions for thruster operation and testing.

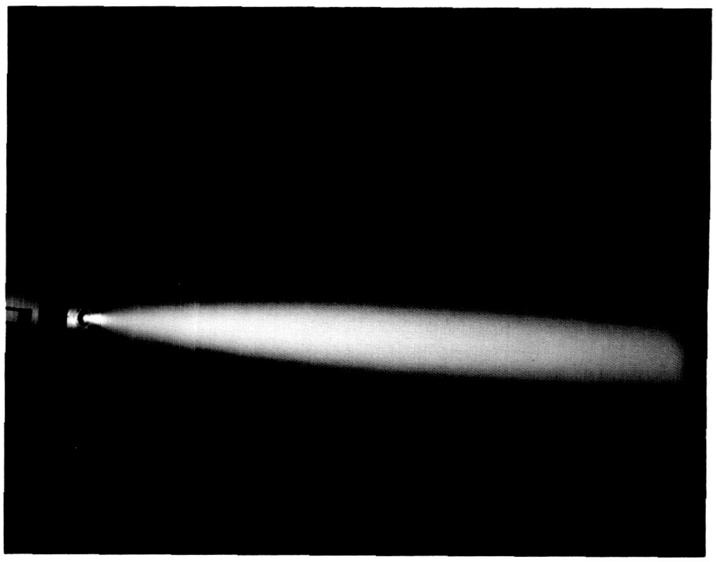
This new pumping speed capability provides Lewis with a facility that exceeds any national vacuum system that we have been able to identify, with the possible exception of the Mark I facility at the U.S. Air Force's Arnold Engineering Development Center.

Lewis contact: Ronald R. Roskilly, (216) 433–2432
Headquarters program office: OAST

250-kW Test Stand for Magnetoplasmadynamic Thruster

The magnetoplasmadynamic (MPD) thruster has propulsion applications for orbit raising, maneuvering of large space systems, and interplanetary missions. The thruster is a low-pressure, high-current arc that produces electric and magnetic fields which accelerate a plasma to very high speeds. The high thruster specific impulse (1000 to 5000 sec) minimizes propellant requirements and thus the demands for mass transfer to low Earth orbit. Potential MPD thruster missions in the next two decades will probably employ solar or nuclear electric power systems in the 30- to 250-kW range. Farther term missions with interplanetary propulsion applications will use nuclear power systems with the capability of many megawatts.

NASA Lewis has begun a program to explore the technology of MPD thrusters operating in the 30- to 250-kW range. Experimental and analytical efforts are under way to determine thruster specific impulse and efficiency limits on a high-power test stand. The test stand is made up of the arc power supplies, an electrode/magnet cooling system, a thrust stand, and a control console. Four welding power supplies are configured to provide about 90 V at 3000 A with expansion capability to 4500 A. The arc is started with argon by using a 1000-V supply in parallel with the 3000-A power supply. The high current supply is protected from the high voltage by water-cooled diodes. Two water cooling circuits operating at 10 atm each provide about 8 gal/min of water to the thruster and the applied field solenoidal magnet. The thrust stand is an inverted pendulum design presently configured to measure thrust up to 10 N.



MPD thruster in operation

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The initial operating capability includes inert gas propellants, nitrogen, hydrogen, and N_2/H_2 mixtures. A commercial plasma generator was modified to operate at chamber pressures of 10 to 100 torr, arc currents from 500 to 3500 A, and applied magnetic fields up to 0.4 T. Performance characterization of the water-cooled MPD thruster will provide details of operating modes, thermal efficiency, specific impulse, and thrust efficiency for a variety of propellants.

Lewis contact: James S. Sovey, (216) 433–2420
Headquarters program office: OAST

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First Tests on New Lewis Cryogenic Turbo-machinery Test Stand

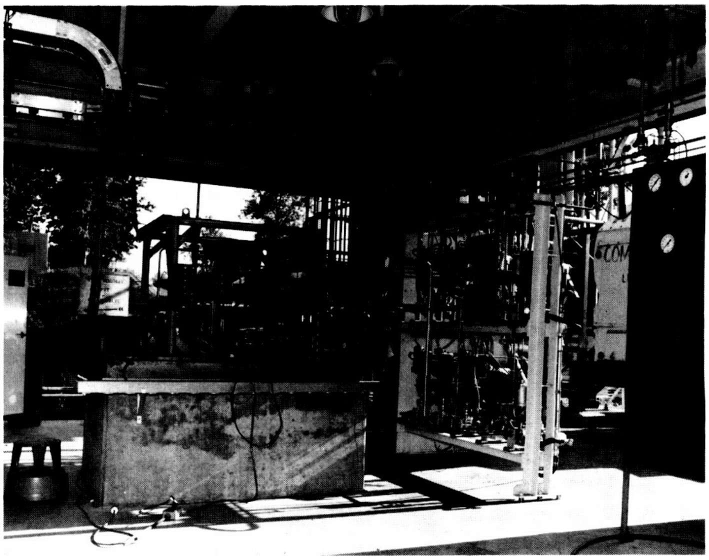
A series of liquid-oxygen seal designs and concepts are being evaluated in the first experiments on the new NASA Lewis turbo-machinery test stand at the Rocket Engine Test Facility (RETF). The facility can rotate at speeds to 100,000 rpm while testing fluids that include liquid hydrogen, liquid oxygen, liquid nitrogen, and water at pressures to 5000 psi. Test fluid flow rates vary from 3 to 36 lb/sec of liquid oxygen and 1 to 6 lb/sec of liquid hydrogen, depending on system operating pressure. Turbine drive fluid capabilities include gaseous nitrogen, gaseous hydrogen, and combustion gases.

Lewis is experimentally investigating liquid-oxygen turbopump shaft hydrodynamic seals that contribute to the overall performance of advanced liquid hydrogen–liquid oxygen propulsion rocket engines. The initial test objectives are to improve the capability of predicting lift-off seal performance during design analyses and to determine seal sensitivity to manufacturing tolerances that cause face seal runout and shaft axial motion. Previous data were very limited because a unique and complex test facility like the RETF is required to obtain such data.

Initial test fluids are liquid nitrogen and liquid oxygen. Seal clearances and leakage rates for a range of speeds and pressure drops are being measured to provide data for this seals program.

Other near-future testing on this stand will support a space shuttle main engine helium-purge, liquid-oxygen seals program and turbo-machinery technology programs for orbit transfer vehicles.

Lewis contact: Scott D. Meyer, (216) 433–2607
Headquarters program office: OAST



Cryogenic turbomachinery test stand

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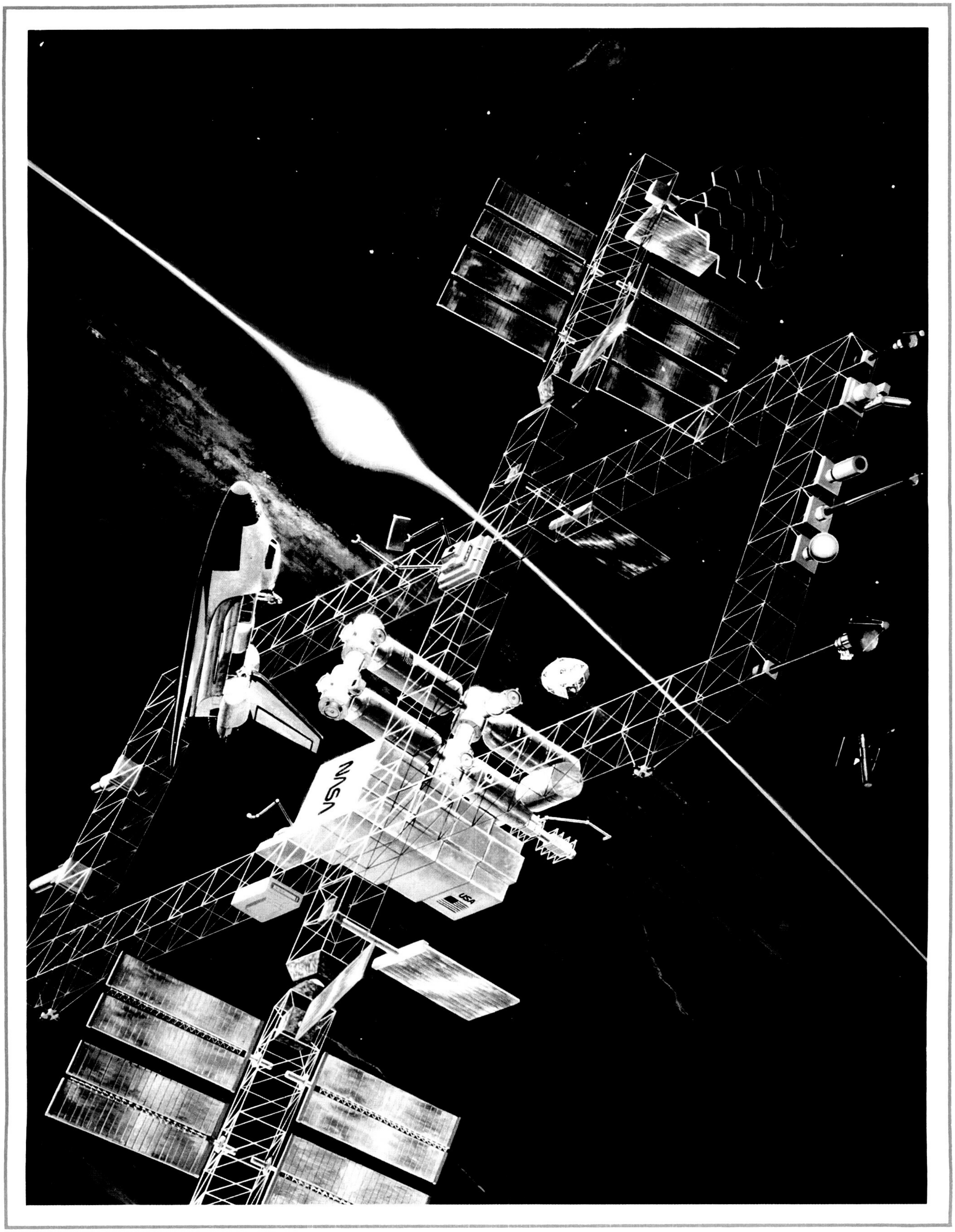


Space Power

Strategic Objectives

- To remain in the forefront as the NASA center for space power systems R&T and development in order to meet current and future national needs.
- To successfully develop the space power systems for the space station.
- To be the NASA center responsible for the development of all future space power systems that require advances in technology and are first of a kind.

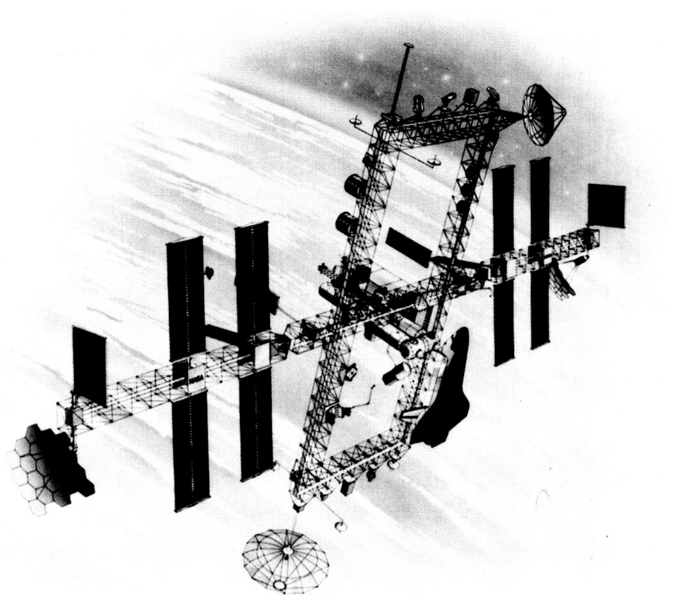
Programs

Space Station Systems

The Lewis Research Center's Space Station Systems Directorate is responsible for managing the design, development, and future operations of the electric power system for the space station and its two platforms—from power generation and storage to power management, distribution, and conversion of power for selected users. Presently, the power system consists of 75 kW of photovoltaic arrays and NiH_2 batteries for the first phase of power generation and storage with the first launch of 18.75 kW occurring in 1994. The power will be distributed via a 20-kHz power distribution system. A decision is planned in 1990 for the second phase of the space station program. The second phase includes the addition of 50 kW of solar dynamic power generation with thermal storage.

In addition to managing the prime contractor for the power system development, the Directorate will also manage many supporting tasks to reduce potential power system risks in areas where Lewis has particular expertise. The Directorate, along with other Center organizations, is supporting the planning for the use and evolution of the station. Lewis has signed an memorandum of understanding with the NASA Johnson Space Center to support them in developing the space station propulsion system. In addition, Lewis has negotiated and signed a contract with Rocketdyne, the prime contractor, for the electric power system.

Lewis contact: Ronald L. Thomas, (216) 433-2968
Headquarters program office: OSS



Space station

CSTI High-Capacity Power—SP–100

The SP–100 Program was established in 1983 by the Department of Defense, the Department of Energy, and NASA as a joint program to develop the technology necessary for military and civil space nuclear power systems. In 1986 the SP–100 Program started a multiyear-effort Ground Engineering Systems (GES) Development Program to design, develop, and demonstrate at ground test sites the operation of the major subsystems of a 100-kWe nuclear/thermoelectric power system. The reference flight system design was completed by the GES contractor (General Electric) in mid-1988.

During fiscal years 1986 and 1987 the NASA SP–100 Advanced Technology Project was devised to maintain the momentum of promising technology advancement efforts started during phase I of SP–100 and to strengthen, in key areas, the chances for successful development and growth of space nuclear reactor power systems for future space applications.

In fiscal 1988, the Advanced Technology Project was incorporated into NASA's new Civil Space Technology Initiative (CSTI). The CSTI Program was established to provide the foundation for technology development in automation and robotics, information, propulsion, and power. The CSTI High-Capacity Power Program builds on the technology efforts of the GES Program, incorporates the previous NASA SP–100 Advanced Technology Project, and provides a bridge to NASA's Project Pathfinder, a fiscal 1989 new start. Pathfinder's purpose is to further develop emerging innovative technologies that will allow a range of missions focusing beyond Earth orbit into the solar system, on establishing a lunar outpost, and on transporting humans to Mars.

The elements of CSTI high-capacity power development include conversion systems, thermal management, power management, system diagnostics, and environmental interactions. The goals of CSTI development include advances in all these technologies to provide increases in power densities from 20 W/kg for the 100-kW GES system to 80 W/kg for the 2.5-MWt GES reactor. Advanced thermoelectric materials are projected to increase specific power from 20 W/kg to about 40 W/kg while approaching 200-kWe output. Development of free-piston Stirling power conversion will further increase specific power to 80 W/kg and 800 kWe output for the GES reactor. Technology advancement in all areas, including advanced materials, is required to ensure high reliability and the 7- to 10-year lifetime demanded for future space nuclear power systems. The overall program will develop and demonstrate the technology base required to provide a wide range of modular power systems with all these attributes plus mission independence from solar and orbital attitude requirements.

Lewis contact: Jerry M. Winter, (216) 433–6133
Headquarters program office: OAST

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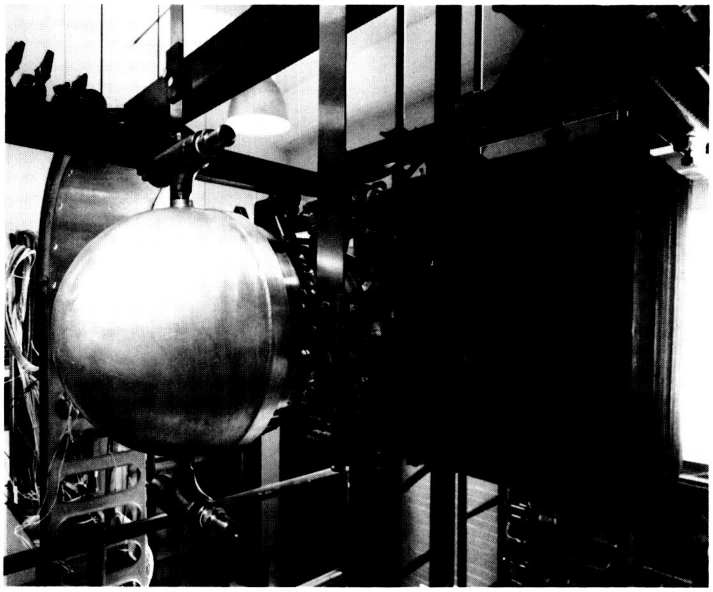
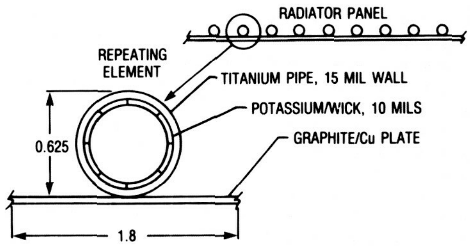


Stirling 12.5-kWe space power research engine

Materials

Preliminary Feasibility Studies of Graphite-Fiber-Reinforced Copper Matrix Composites for Space Power Radiator Panels



DESIGN CONSIDERATIONS:
- FUNDAMENTAL FREQUENCY >100 Hz (HIGH MODULUS/DENSITY)
- THERMAL EXPANSION MATCHES Ti HEAT PIPE (TAILORED CTE)
- THERMAL CONDUCTANCE PERPENDICULAR TO HEAT PIPE MATCHES Be (HIGH THERMAL CONDUCTIVITY)
- WEIGHT EQUIVALENT TO Be (LOW DENSITY/DESIGN COMPENSATION)

Gr/Cu composite space power radiator panel

There are several designs for space power radiators. In a generic radiator concept excess heat from the power conversion subsystem is sent to the radiator along a titanium heat pipe. The heat pipe is joined to a radiator panel that both radiates heat and conducts the heat to a cooler area for radiation into space. Current designs call for beryllium or niobium alloys as the radiator panel material. Each of these materials has potential drawbacks. Beryllium is a lightweight, high-modulus material but has safety and handling problems. Niobium alloys have good structural properties but are poor thermal conductors.

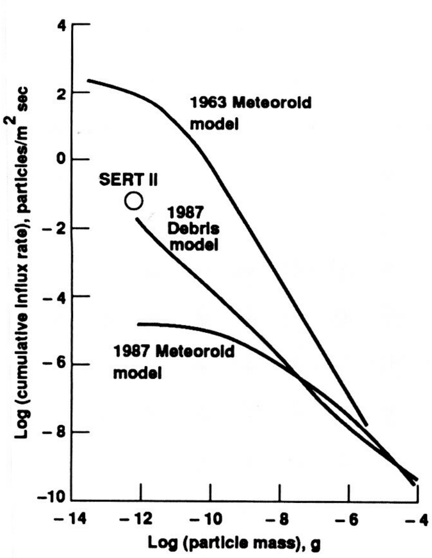
Graphite-fiber-reinforced copper matrix (Gr/Cu) composites offer potential as lightweight, high-modulus, high-thermal-conductivity materials for space radiators. Ultra-high-modulus graphite fibers have been developed with thermal conductivities equivalent to that of copper, densities equivalent to that of beryllium, and elastic moduli two to three times greater than those of beryllium. Composites of ultra-high-modulus graphite fibers in a copper matrix offer an advanced material that could reduce the mass and increase the efficiency of space power radiators.

Although the anisotropy of Gr/Cu composites imposes a severe thermal conductivity penalty in the short transverse direction, the properties are still comparable to those of competing materials in this direction and are far superior in the longitudinal direction. Other properties of the Gr/Cu composites also show good potential. The longitudinal modulus of elasticity is very high and remains virtually constant up to 750 °F. The longitudinal tensile strength is promising at elevated temperatures, but the transverse tensile strength is very low and will probably require angle plying.

Lewis contact: David L. McDanels, (216) 433–5525
Headquarters program office: OAST

Durability of Solar Dynamic Concentrators in Space Micrometeoroid and Debris Environment

Mirror reflector surfaces used to concentrate sunlight for solar dynamic power systems must survive and operate efficiently in the low Earth orbital environment. Two natural hazards presented by this environment are (1) the particulate environment, consisting of both naturally occurring micrometeoroids and artificially created debris, and (2) highly corrosive atomic oxygen. Thin, highly reflecting surfaces such as silver must be protected from both oxidation by atomic oxygen and hypervelocity particulate impact. NASA Lewis has identified thin metal oxide protective films that are durable in atomic oxygen and permit high solar reflectance.



Models and SERT II measurements of micrometeoroids and debris in Earth orbit

Penetration of these protective thin films by micrometeoroid or debris particle impact may allow oxidation of the underlying silver reflector material. A sufficiently high flux of micrometeoroid and debris particles can reduce the efficiency of a solar concentrator system. Early micrometeoroid and debris models indicated the presence of a substantial flux of particles. A more recent (1987) micrometeoroid and debris model based on penetration data showed seven orders of magnitude lower micrometeoroid fluxes than proposed by the earlier model. The result of Lewis' micrometeoroid experiment on the SERT II spacecraft suggests that the more recent model describes the particulate environment more accurately. As a result, micrometeoroid and debris particle impacts on solar concentrators do not appear to be of significant consequence to their long-term durability. For a 10-year mission the total impact area is predicted to represent less than 1 percent of the concentrator area.

Lewis contacts: Daniel A. Guliano, (216) 433–2310; Michael J. Mirtich, (216) 433–5616; Bruce A. Banks, (216) 433–2308
Headquarters program office: OAST

Advanced Solar Concentrator Materials Evaluated for Space Environment Effects

NASA Lewis is conducting an Advanced Solar Dynamic Technology Development Program for applications beyond the late 1990's. A major element in that program is the development of the technology for very lightweight, durable, optically efficient concentrators of both the reflecting and the Fresnel types. Tasks are included to identify and develop innovative concentrator concepts that are automatically deployable without astronaut assistance and advanced reflective and Fresnel lens panel concepts.

A critical challenge is finding the optimum combination of materials and fabrication methods so that the concentrators will survive the punishing effects of the low-Earth-orbit environment, primarily atomic oxygen, ultraviolet light (UV), and thermal cycling. Atomic-oxygen-resistant materials have been identified and are now being experimentally verified. Methods of fabricating candidate reflective and refractive elements are being established. Eventually the most promising candidates will have to pass tests in atomic oxygen, UV, and combined UV, vacuum, and thermal cycling environments.

Experiments to date have identified several promising combinations of materials and substrate concepts

for reflectors. Sandwich panels have been made with aluminum or titanium face sheets and aluminum foam or honeycomb cores. One-foot-square dished panels have been accurately contoured (a slope error of less than 1 milliradian). These samples weighed 1.1 kg/m^2 (the goal is 1.0 kg/m^2). Mirrors have been produced by depositing silver on a sol-gel smoothed surface of stainless steel foil. Sol-gel is a chemically produced glass that is resistant to atomic oxygen attack and is a prime candidate material for making refractive lens. Very thin glass mirrors have been bonded to a honeycomb sandwich.

Two promising reflecting concentrator concepts are under development. One is an assembly of rigid curved radial panels (each shaped like a wedge of orange peel). The panels are hinged in a manner that allows the concentrator to be folded up into a compact package for launch and automatic deployment on orbit. The other is a one-piece, thin membrane dish that can be rolled up into a tube-like shape for launch and deployed by unrolling.

Lewis contact: Joseph M. Savino, (216) 433–5531
Headquarters program office: OAST

Fiber Reinforcement Increases Creep Resistance of Refractory Metals

Advanced materials are needed in order to meet the stringent size, weight, and performance requirements of future space power systems. The niobium–1 percent zirconium alloy, although displaying many desirable properties, does not have sufficient creep strength for the times and temperatures of current power system designs. Reinforcing Nb–1Zr with 50-vol % thoriated tungsten fibers offers a significant strength increase over monolithic niobium alloys.

Both unidirectionally reinforced and angle-plied composites were fabricated at NASA Lewis by our patented arc-spray process. Creep tests were performed in vacuo, and the results were compared with those for monolithic Nb–1Zr and PWC–11, an experimental dispersion-strengthened niobium alloy (Nb–1Zr–0.01C). The fiber-reinforced material displayed superior creep resistance, demonstrated by the time to reach 1 percent strain, even when examined on a stress/density basis.

Research is continuing on characterizing how interdiffusion between the fiber and the matrix affects long-term creep properties, examining transverse creep properties, and extending the data base to longer times for easier extrapolation of these data to required mission times.

Bibliography

Petrasek, D.W.; and Titran, R.H.: Creep Behavior of Tungsten/Niobium and Tungsten/Niobium–1 Percent Zirconium Composites. DOE/NASA–16310–5, NASA TM–100804, 1988.

Westfall, L.J.: Preliminary Feasibility Studies of Tungsten/Niobium Composites for Advanced Space Power Systems Applications. NASA TM–87248, 1986.

Lewis contact: Toni L. Grobstein, (216) 433–5524
Headquarters program office: OAST

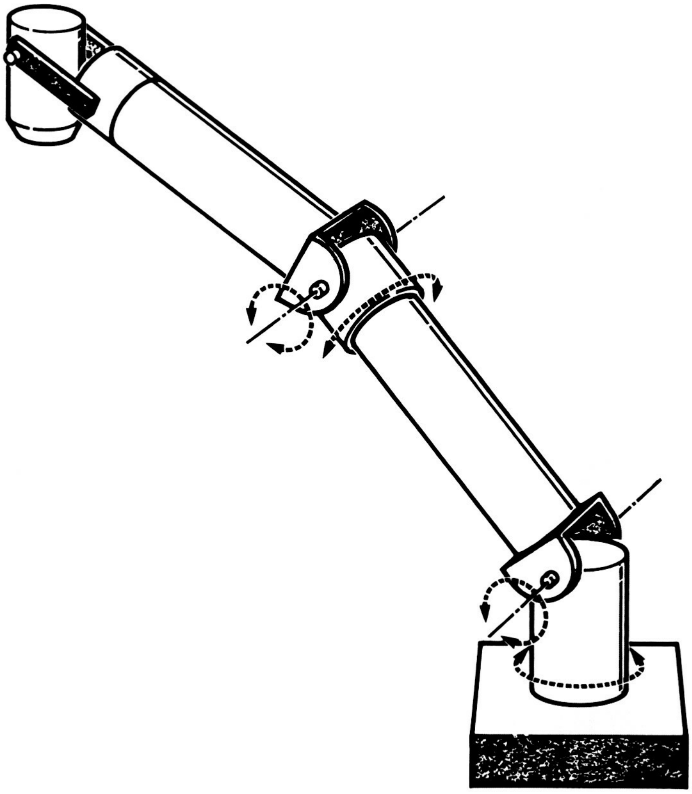
Structural Mechanics

Robotic Manipulators for Space

Robotic manipulators used in space applications are expected to operate under microgravity conditions. Base reactions of a space manipulator are directly exerted on the supporting space structure, which would be typically a space vehicle (e.g., a space shuttle) or a space station. These reactions should be as small as possible to reduce their influence on the dynamics of the supporting space structure. Control of the space structure is a crucial consideration in space applications. Furthermore, in delicate experiments conducted in space the test specimens will have to be moved carefully, without subjecting them to excessive accelerations and jerks, but at reasonably high speeds. It follows then that minimizing base reactions and limiting end-effector accelerations and jerks are important performance objectives for space manipulators.

NASA Lewis has developed a trajectory generation method for designing space manipulators. The approach employed a manipulator with redundant kinematics. The method was implemented in two steps. First, the end-effector trajectory was developed to satisfy the acceleration and jerk limitations. Second, the joint trajectories were developed to minimize a quadratic cost function in base forces and base moments. Kinematic redundancy of the manipulator was employed here.

A three-revolute manipulator (not shown) executing planar motions was considered as an example. The end-effector trajectory was divided into equal time steps. During the first step an exhaustive search method was used to determine the initial configuration as well as the initial parameters that would minimize the cost function. Then unconstrained optimization was carried out for the subsequent steps to determine the optimal trajectory. In the resulting base reactor cost functions the relative magnitude of the optimal curve was consistently close to zero, indicating that the ideal objective of zero reaction is within reach. The results show a great promise for using kinematic redundancy in minimizing base reactions.



Conceptual design of traction-driven manipulator with two-degree-of-freedom joints

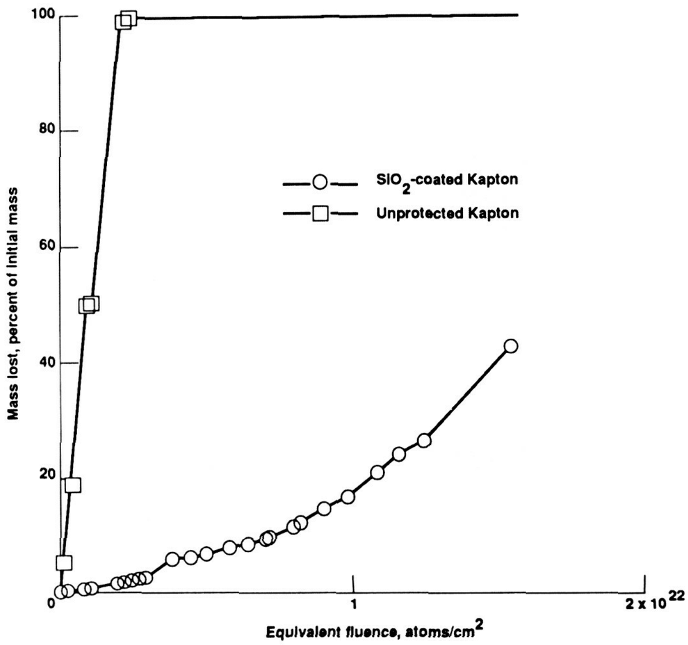
Lewis contact: Charles Lawrence, (216) 433-6048
Headquarters program office: OAST

Life Prediction

Atomic Oxygen Durability Evaluation of Space Station Solar Array Components

Atomic oxygen, the most predominant species in the Earth's low orbital environment, is highly reactive to organic materials and some metals. Polyimide Kapton solar array blankets and fiberglass-epoxy structures used for the deployment of the space station's solar arrays are vulnerable to oxidation by atomic oxygen unless their surfaces are protected from exposure to this environment. Unprotected Kapton in the low Earth orbital environment would quickly oxidize until structural or electrical failure of the solar array resulted. Unprotected fiberglass-epoxy structures would lose their epoxy from the surface through oxidation, thus exposing the friable glass fibers, which could contaminate the space station's components and local environment.

NASA Lewis has developed laboratory facilities to simulate the effects of atomic oxygen interaction with materials in the low Earth orbital environment. These facilities, in conjunction with spaceflight test results, have been used to evaluate the effectiveness of thin-film, atomic-oxygen-protective coatings. These coatings substantially increased the durability of materials that otherwise would be readily attacked by atomic oxygen.



Effectiveness of SiO_2 coatings on Kapton

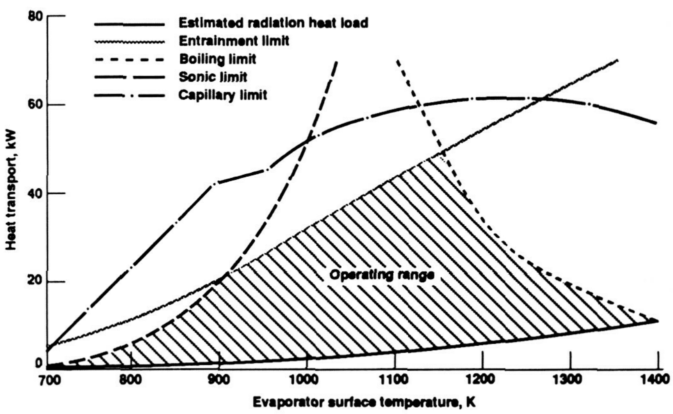
Lewis contact: Sharon K. Rutledge, (216) 433–2219; Bruce A. Banks, (216) 433–2308
Headquarters program office: OAST

Steady-State Heat Pipe Code

Successful design of space heat rejection systems with heat pipe radiators requires that the individual heat pipe operating envelopes be analytically predictable. To this end, NASA Lewis has developed a steady-state heat pipe computer code to serve as an analytical tool for a wide range of pipe and wick geometries and working fluids.

The code has the unique capability of using prescribed evaporator operating conditions as input. The option of several operating modes is also available.

For example, as the heat pipe evaporator surface temperature is varied, the program can be used to generate, by iteration, the



Heat pipe operating range

bounding curve of maximum heat transport rate defined by the lowest of several possible operating limits encountered. Among the limits capable of being identified are the entrainment, boiling, sonic, and capillary limits. Typical limit envelopes are indicated in the figure for a potassium heat pipe used in the SP–100 radiator, along with the operating line defined by the radiative heat transfer from the heat pipe condenser to space. With the limit envelopes identified, heat pipes can be designed with the necessary operating margins to preclude failures caused by operating limit encounters. The heat pipe operating range is indicated by the shaded area in the figure. The code has been validated by comparing the results with those generated by other codes and with experimental performance data obtained from SP–100 heat pipe tests.

Lewis contacts: Albert J. Juhasz, (216) 433–6134; Karl W. Baker, (216) 433–6160
Headquarters program office: OAST

Thermal Energy Storage for Advanced Solar Dynamic Receivers

Thermal energy storage (TES) is a critical element in solar dynamic systems. It provides the system with constant-temperature energy even though in Earth orbit the energy from the Sun is received sporadically. Fluoride salts such as lithium fluoride (LiF) and sodium fluoride (NaF) have received most attention because of their high heats of fusion at the temperatures of interest to the system. However, such salts change density and hence volume as they change phase (liquid/solid). These salts also have poor conductivity, which can vary the heat flow to the working fluid as the salt freezes and thaws continuously during orbit.

Because of the higher densities of metals, metal TES can lead to smaller and lighter solar heat receivers than salt TES. Several metals and metal alloys with good conductivities and high heats of fusion are thus being considered as TES materials in advanced solar dynamic systems. Two of these candidate materials are germanium and nickel silicide. The principal concern with these metals is their corrosivity. Oak Ridge National Laboratory (ORNL) is developing these metal systems under a Lewis-sponsored program.

The present effort in fluoride salts is focused on the behavior of voids formed as the liquid TES material solidifies. A void immediately adjacent to a high-heat-flux area of the container as the spacecraft emerges into the Sun can cause overheating of the containment structure. In the other extreme, where such an area is filled with solid salt, the melting salt seeking to expand can deform the container. At present a designer can increase containment mass to circumvent the problem. Advanced designs, however, need a better understanding of voids in TES to achieve the goals of lighter weight, more efficient heat receivers.

Predictions of what voids will occur under microgravity, and where, have been based largely on one- and two-dimensional analyses and on limited ground-based tests. Lewis has contracted ORNL to perform three-dimensional analysis of the process of heat transfer, energy storage, fluid movement, and void location under microgravity. The results will form the basis for comparison with the test results to be obtained from a Lewis flight program.

ORNL has the capability to computerize this complex, transient phenomenon. The computer program divides the problem into seven discrete heat transfer or fluid flow mechanisms. These mechanisms include heat conduction through the salt's liquid and solid phases, radiation from the container wall through the void to the salt, and container conduction. Much of the effort, however, is in describing the progression of the liquid-solid interface during "sun" and "shade." Equally significant is the interface between the liquid and the void, where surface tension effects, usually negligible in normal gravity, will be dominant under microgravity.

Lewis contacts: David Namkoong, (216) 433–6301; Miles O. Dustin, (216) 433–6161
Headquarters program office: OAST

Space Station Power Systems

Mast Material Test Program

The space station's electrical power system will be designed to operate in the low Earth orbital environment for 15 years. This environment includes solar (ultraviolet) radiation, atomic oxygen, micrometeoroids, and space debris. The materials used in constructing the power system must therefore be able to withstand this relatively long-term exposure.

The power-producing elements of the system are the solar array "wings." These wings consist of two Kapton blankets covered with silicon solar cells and supported by a deployable, continuous-longeron mast. The mast is used for the on-orbit deployment of the solar array blankets, and it provides structural support to the extended blanket pair. The primary mast structural elements, longerons that run the length of the mast, are made of fiberglass and epoxy.

The Mast Material Test Program (MAMATEP) was established to ascertain the need for protecting the solar array mast of the power system from environmental degradation. In case protection would be necessary, various mast protection techniques were concurrently evaluated. The requirements for the mast protection material are typical of the requirements for other space station protection materials with one addition—flexibility. The stowed mast will be subjected to a bending strain of about 1.5 percent. Materials used to protect rigid structures may thus not be appropriate for protecting the flexible mast material.

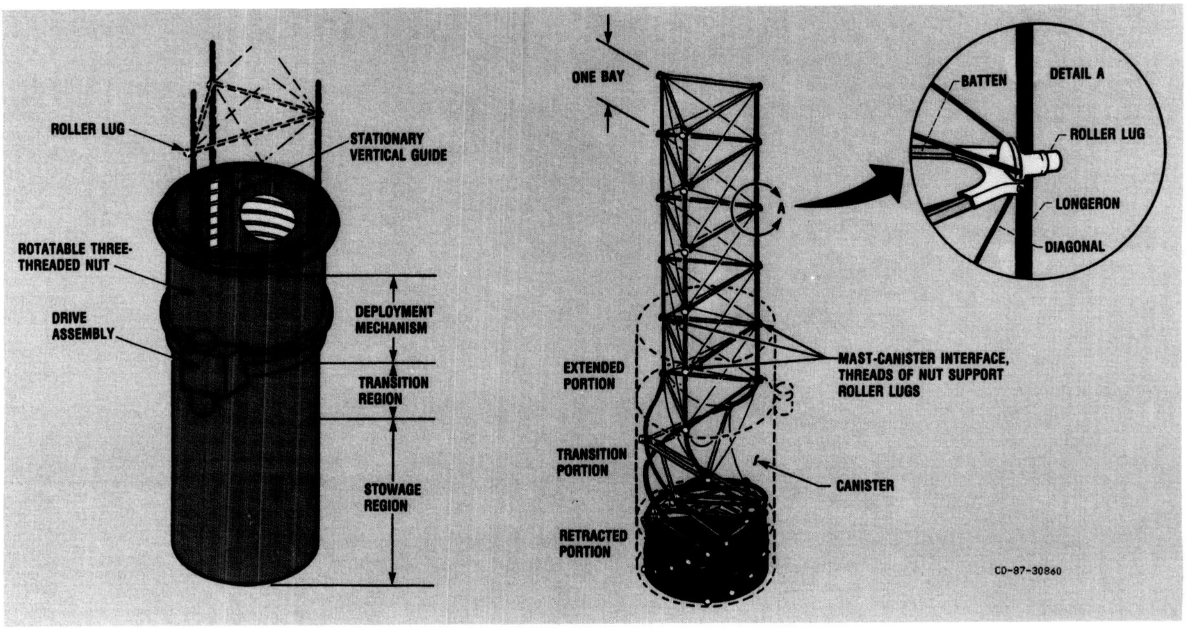
The leading protection material candidates are a nickel-gold-indium tin eutectic and an aluminum-braid sheath. A clear silicone coating and a thermal control paint were also evaluated. Preliminary findings indicated that, although the mast may not require protection from the orbital environment, a "protection" technique may be necessary to reduce the rate of material degradation or to contain the degradation products—products that could contaminate the space station. This in-house program was completed at the end of fiscal 1988. The fiberglass-epoxy mast material and the protective materials evaluated were obtained from AEC-Able Engineering and Composite Optics, Inc.

Bibliography

Ciancone, M.L.; and Rutledge, S.K.: Mast Material Test Program (MAMATEP) NASA TM-100821, 1988.

Lewis contact: Michael L. Ciancone, (216) 433-5387

Headquarters program office: OSS



Deployable, continuous-longeron mast

Development of Advanced Silicon Solar Cells for Space Station

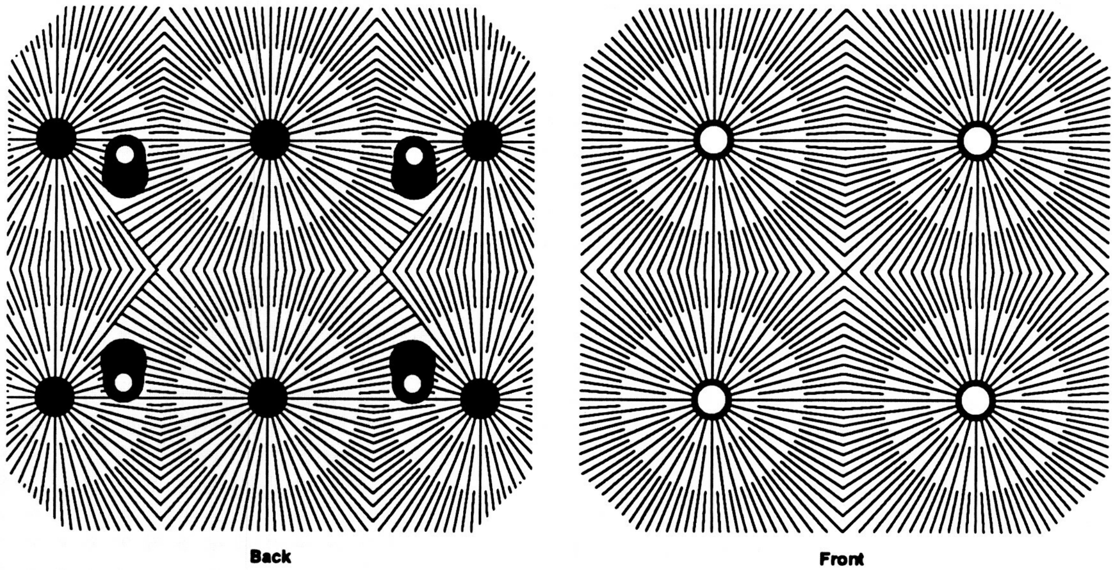
Large gridded-back silicon solar cells are being developed for the space station, under a NASA Lewis contract, by Spectrolab, Inc. Specific issues being addressed are high efficiency, low cost, and the ability to manufacture the cells in high volume (~200 kW/yr). Several advanced features are incorporated in the design to minimize cost and to enhance performance.

The solar cell is the largest, a quasi-square, 8 cm by 8 cm, that can be fabricated from a single 4-in.-diameter silicon wafer. A large cell with a minimum power output greater than 1 W will minimize the cost of manufacturing space station arrays.

A concentric-ring grid design was chosen for both the front and back of the cell. The four laser-scribed wrapthrough points for the front N+ contacts and six P+ back contacts are all weldable on the back side to facilitate automated resistance welding during array assembly. The gridded-back contact results in a low thermal-alpha with the infrared-transparent Kapton substrate array design. The cell thus improves space station array performance by operating at lower temperatures in space.

A limited pilot-line production run was completed on the advanced design to establish initial performance and to yield information. The cells delivered to Lewis will be used to support other on-going space station activities.

Lewis contact: Bernard L. Sater, (216) 433-5291
Headquarters program office: OSS



Gridded contact design of 8-cm by 8-cm wrapthrough solar cell

Environmental Protection for Space Station Photovoltaic Array

The space station will operate in low Earth orbit, where the concentration of neutral atomic oxygen is relatively high. The exposed surfaces of the space station will be subject to an energetic flux of atoms. Materials that react with oxygen will degrade. The flexible solar array design makes use in its construction of a number of polymers that are vulnerable to attack by atomic oxygen. The most critical component is the solar array substrate, primarily Kapton. Under a NASA Lewis contract, Lockheed is developing a thin inorganic coating (SiO_2) that can be applied to both sides of virgin Kapton material by using a roll-to-roll vacuum sputtering process. This coating appears to be durable, providing adequate protection to exposed surfaces even when subjected to the array fabrication sequence and the manufacturing environment.

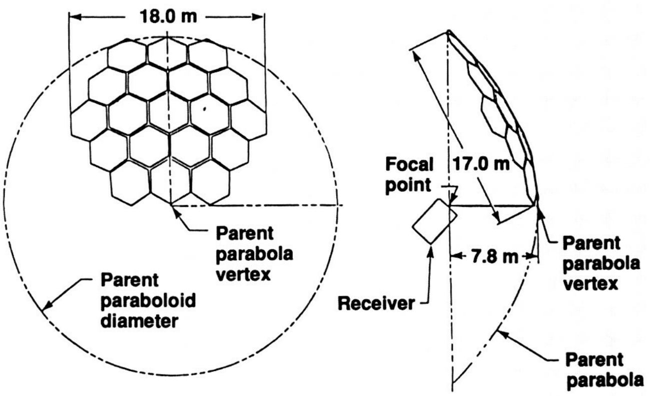
Protective coatings have been evaluated in atomic oxygen plasma ashers as a screening test; but realistic low-Earth-orbit simulation with a neutral atomic oxygen beam source is planned. Two full-size panels and a number of smaller test samples are being fabricated for further testing that will include plasma interaction, thermal cycling, and a flight experiment.

Lewis contact: Bernard L. Sater, (216) 433–5291
Headquarters program office: OSS

Ray-Tracing Optical Analysis of Offset Solar Collector for Space Station Solar Dynamic System

A Brayton-cycle solar dynamic electric power system is being developed for a possible future enhancement of the space station's capabilities. The solar dynamic system uses an offset parabolic collector to reflect solar energy into a cylindrical receiver cavity. To successfully develop the power system, we must understand the flux distributions within the receiver cavity produced by reflections from the offset collector. OFFSET, a detailed ray-tracing computer code, is being developed at NASA Lewis to evaluate the intensity and distribution of the collected solar flux on the inside walls of the receiver.

OFFSET models the offset solar collector for the space station solar dynamic electric power system. This model traces rays from 50 points on the face of the Sun to 10 points on each of 456 collector facets. The triangular facets are modeled with spherical, parabolic, or toroidal reflective surface contour and surface slope errors. The rays are then traced through the receiver aperture to the walls of the receiver. OFFSET is operational on an Amdahl 5860



Offset Newtonian collector geometry

computer and requires less than a minute of run time.

Images of the collector and of the Sun within the receiver produced by this code provide insight into the collector-receiver interface. Flux distribution on the receiver walls, plotted by this code, is improved by a combination of changes to the aperture location and the receiver tilt angle. Power loss by spillage at the receiver aperture is computed and is considerably reduced by using toroidal facets.

Studies are on-going at Lewis in support of the solar dynamic collector development effort with Rockwell-Rocketdyne. The OFFSET code will be made available through COSMIC in September 1988.

Bibliography

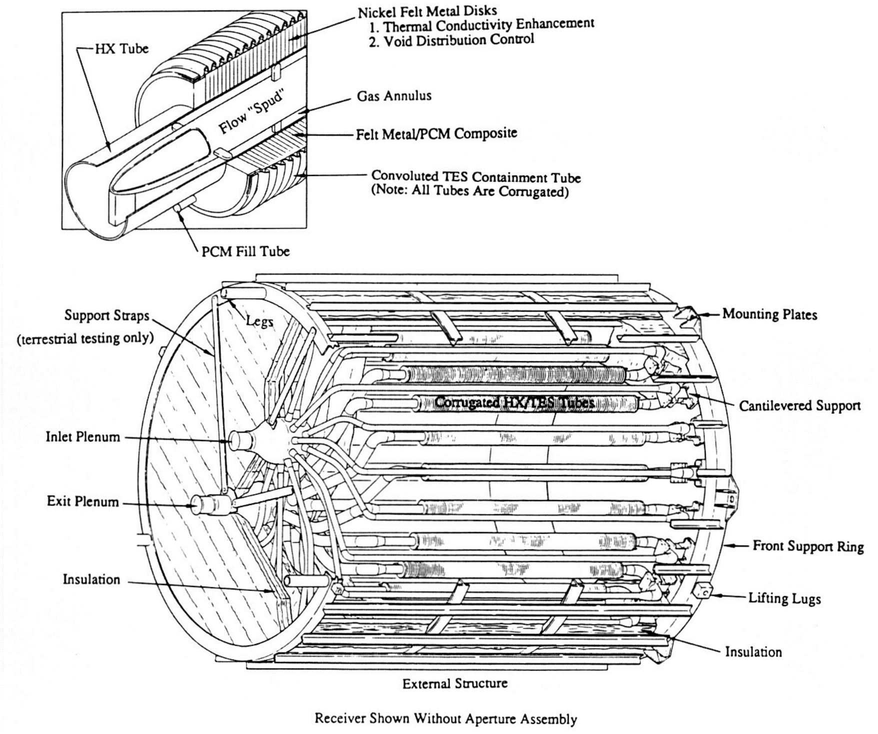
Jefferies, Kent S.: Ray Tracing Optical Analysis of Offset Solar Collector for Space Station Solar Dynamic System. NASA TM–100853, 1988.

Lewis contact: Kent S. Jefferies, (216) 433–5372
Headquarters program office: OSS

Advanced Development of Solar Dynamic Heat Receiver

Because of the severe and unique conditions under which the solar dynamic heat receiver will operate with respect to temperature and material compatibility, analysis and testing are being conducted to resolve issues in key areas. The work is being performed in-house at NASA Lewis and by outside contractors.

The major contracted effort is by Boeing Aerospace under the Space Station Advanced Development Program. The objectives of the 3 ½-year contract, which began in October 1985, are to resolve key technology issues associated with the design, fabrication, testing, and operation of the heat receiver; to validate receiver design and analysis methods; and to provide a receiver testing and operational data base in support of the space station flight hardware design and fabrication. During fiscal 1988 Boeing completed the detailed design of a solar heat receiver for a 25-kW closed Brayton cycle power system and began fabricating a full-scale test receiver. In parallel with the design effort Boeing conducted weld development programs and material compatibility tests to support several heat exchanger tube fabrication processes and material selection. They verified the final tube configuration, prior to fabricating the full-scale



Solar dynamic heat receiver without aperture assembly

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hardware, in 500-hr thermal performance tests on prototypical tube segments.

The full-scale receiver will undergo performance verification tests in a thermal/vacuum facility that simulates orbital conditions. Boeing has nearly completed the design of a solar heat source simulator made from quartz lamps. Long-duration tests of single and paired lamp assemblies were conducted in a vacuum to verify the lamp lifetime under receiver test conditions. Receiver fabrication will be completed in March 1989, and testing will be completed in June.

Lewis contact: Steven D. Johnson, (216) 433–5370
Headquarters program office: OSS

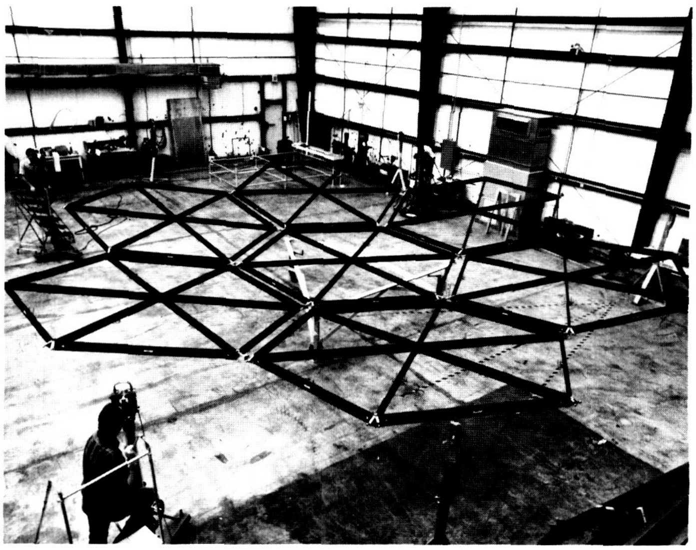
Advanced Development of Solar Concentrator

The Solar Concentrator Advanced Development (SCAD) Program, begun in September 1985, had the objective of developing and demonstrating key solar concentrator technologies required for space station applications. The work is being performed by the Harris Corporation under contract to NASA Lewis.

The SCAD program was broken into three major tasks. Task 1 included conceptual designs and tradeoff studies. Tradeoff parameters included optical performance, orbiter cargo bay packaging, producibility, design flexibility, and durability in the low-Earth-orbit space station environment. A truss hexagonal panel concentrator concept was chosen mainly for its inherent design flexibility and technical soundness.

Task 2, the detailed design of the SCAD concentrator, resulted in an offset parabolic design employing 19 hexagonal panels mapped to a spherical surface. Each panel contains 24 reflective facets that are individually focused to provide an optimum solar flux distribution into the receiver. The panels are connected by self-locking, ball-and-socket latches that provide zero translation displacement in three axes.

Task 3 includes the fabrication and testing of the SCAD concentrator. Fabrication of the panels and latches was completed in March 1988. Fabrication of the reflective facets was completed in October 1988. A major milestone was achieved in April 1988 when the seven central panels were assembled, disassembled, and reassembled with a maximum variation in panel position of 0.004 in. The test successfully demonstrated assembly repeatability of the SCAD concentrator design. Optical testing will be performed in the high bay area of the NASA Lewis Power System Facility in January 1989 and will continue through August 1990.



SCAD concentrator seven-panel repeatability test

The SCAD Program has provided valuable experience to NASA Lewis and space station contractor personnel. Detailed designs, modeling tools, fabrication techniques, concentrator assembly procedures, and test equipment and procedures generated in the program will greatly enhance the upcoming space station solar dynamic flight concentrator development program.

Bibliography

Solar Concentrator Advanced Development Program, Task 1. NASA CR–179489, 1986.

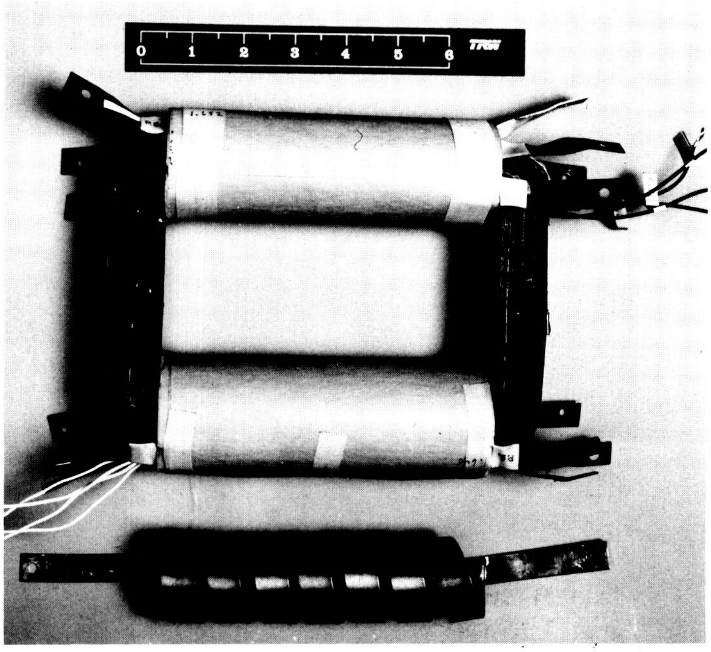
Lewis contact: Todd T. Peterson, (216) 433–5350
Headquarters program office: OSS

20-kHz, 25-kW Space Station Power Transformer

The TRW Power Conversion Electronic Laboratory is developing a 20-kHz, 25-kW power transformer under contract to NASA Lewis as part of the Space Station Advanced Development Program. The transformer is being considered for application in the 20-kHz, alternating current power distribution system of the space station. It will reduce the 440-V distribution voltage to 208 V, provide electrical isolation between systems and subsystems, and facilitate implementation of a single-point grounding system.

The transformer is designed for high efficiency, low weight, and low-leakage inductance. The electrostatic shields between windings will reduce electromagnetic interference. The single-layer, spiral winding technique used for each transformer winding provides good magnetic coupling between the windings and the core for low-leakage inductance and also provides good heat transfer to the magnetic core and the baseplate heat sink. According to present measurements, the transformer will weigh about 19 ½ lb and be 99.36 percent efficient. The total leakage inductance, which includes the lead inductance, was measured at 160 μH. The transformer is thus expected to exceed the performance goals originally specified.

Lewis contact: Francis Gourash, (216) 433–5293
Headquarters program office: OSS



Partially completed 20-kHz, 25-kW power transformer illustrating spiral winding technique

Fast-Switching, High-Power Semiconductor

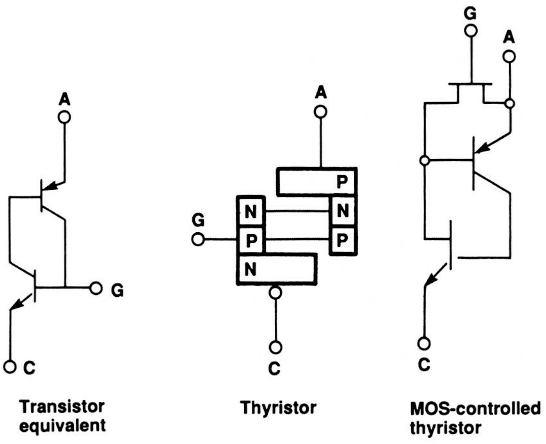
The General Electric Company is presently developing, for space station, a 1200-V, 40-A metal-oxide-semiconductor-controlled thyristor (MCT). This high-speed switch will be used in power-conditioning equipment such as inverters to convert photovoltaic array output to a sine wave for simple distribution, battery charge and discharge units, array regulators to limit potentially damaging voltage excursions, power supplies for motor applications, and other uses.

Because of its fast switching speeds, on the order of 1 μsec, this device will be well suited for switching functions. The low voltage drop across the device of 1.2 V at 40 A and 150 °C makes for simple, cost-effective packaging where the switch is used as a power grid protection device.

The MCT has four layers like a common thyristor. What differentiates these two technologies is that the gate-turnoff field-effect transistor (FET) is built into the MCT. The FET's divert the main body currents momentarily in order to commutate (switch off) the thyristor portion of the MCT. Because of this turnoff mechanism the MCT can be exposed to extremely rapid voltage changes (dV/dt), on the order of 20,000 V/μsec, alleviating one of the needs for snubbers.

This semiconductor can also be used in many ground-based power applications where bipolar or FET technologies are presently used.

Lewis contact: Sam W. Hussey, (216) 433–8312
Headquarters program office: OSS



Schematics of representative semiconductors

Space Station Inverter

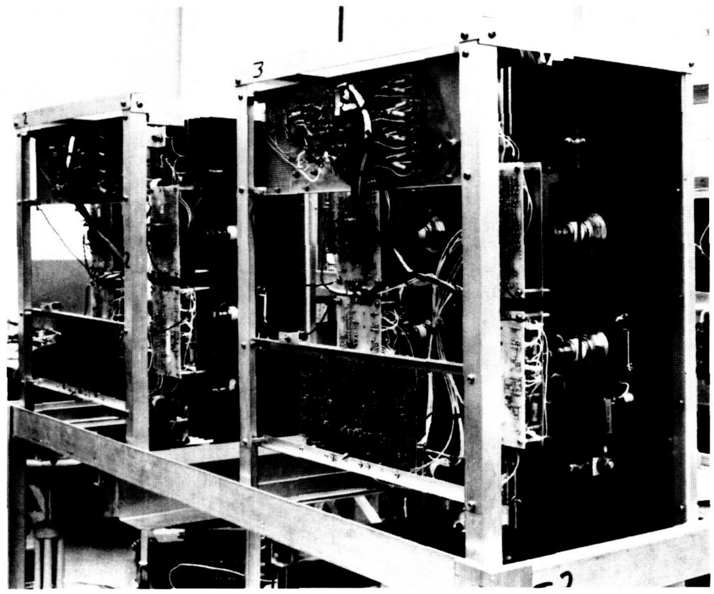
TRW has designed and developed, for the space station electrical power system, an inverter subsystem that converts the photovoltaic array output power to 20-kHz, 440-V alternating current with low distortion. This inverter allows for ease of voltage transformations, galvanic isolation (providing greater noise immunity), and electrical grid protection.

The basic inverter element is a 5-kW current feed push-pull topology. Under steady-state conditions the inverter operates as a quasi-resonant circuit. This characteristic reduces the switching losses that are attendant with all solid-state converters. Total efficiency, including housekeeping power, is 90 percent.

With voltage feedback the inverter can operate from no load to short circuit with no detrimental effect on the equipment. A system clock is employed to parallel many inverters in order to match the feeder size of the space station (~25 kVA).

The technology developed on this contract can also be used in other space-based, high-power applications where weight, efficiency, and simplified system control are prime drivers.

Lewis contact: Sam W. Hussey, (216) 433–8312
Headquarters program office: OSS



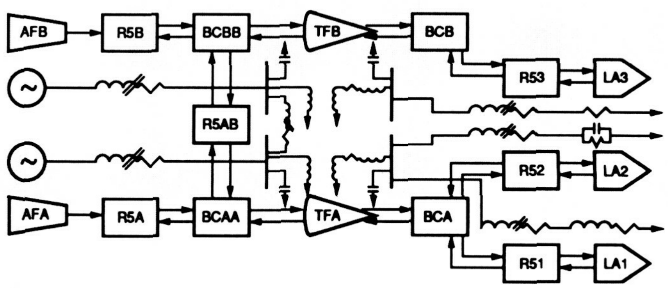
Space station inverter

Computer Modeling of Test Beds

NASA Lewis, supported by Rocketdyne and Virginia Polytechnic Institute, is developing computer models of power management and distribution test beds. The models developed so far include solar arrays, direct-current battery storage and regulation systems, resonant inverters, transmission lines, switch gear, and the solar dynamic simulator. EASY5, a simulation tool developed by Boeing Computer Services, has been primarily used in this effort. These models are able to simulate the system dynamics at the 20-kHz level. They are validated against test data supplied by the test beds. The validated models can then be used for design purposes in the space station C/D phase, as well as to predict test bed performance under different operating conditions.

Lewis contact: Narayan V. Dravid, (216) 433–2733
Headquarters program office: OSS

Model of typical power distribution and control unit with two test sources and three test loads



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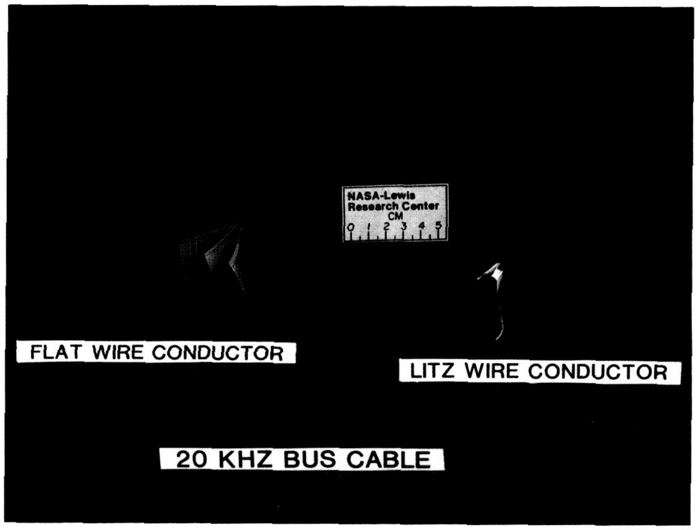
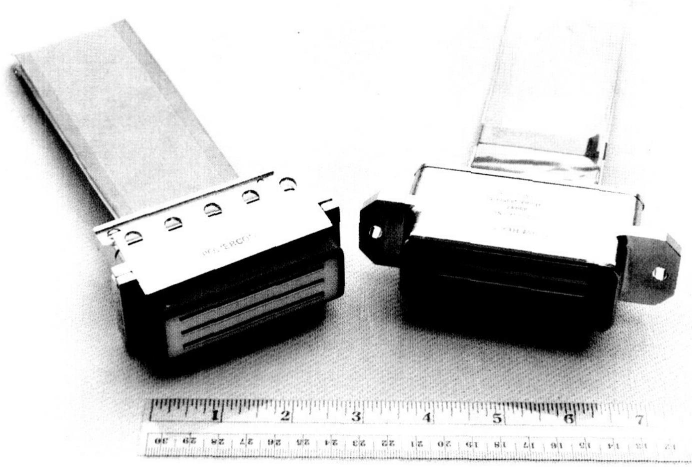
20-kHz Power Cable

W.L. Gore has developed, for NASA Lewis, a high-power, low-inductance, 20-kHz cable. The low inductance will reduce the external magnetic field of the cable, minimize the cable voltage drop, and reduce the crosstalk between loads. This second-generation cable uses solid, flat foil conductors instead of the "Litz" wire conductors used in the first design. The advantages of the solid, flat foil design over the Litz wire design are that the cable is more flexible, easier to manufacture and terminate, and faster outgassing. The foil conductors are covered with a solid dielectric coating; the filler and outer jacket are a gas permeable dielectric material that allows for the improved outgassing. This cable will be installed in the Lewis space station test bed for component and system evaluation.



20-kHz power cable

Lewis contact: Gregory V. Schmitz, (216) 433-5322
Headquarters program office: OSS



20-kHz power connector

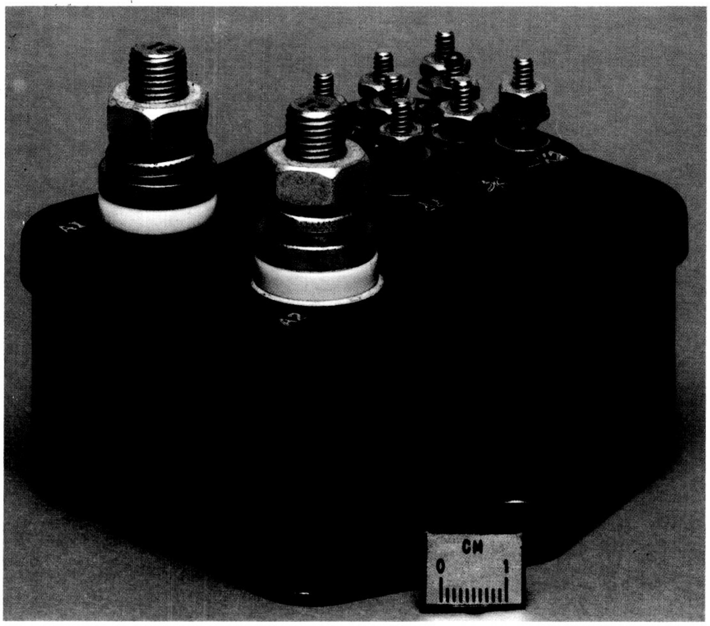
20-kHz Power Connector

G. & H. Technology, Inc., under contract to NASA Lewis, has developed a prototype connector for terminating the 20-kHz power cable. This device is rated for 30 kVA, 440 V ac rms, and 20 kHz. The basic design is for an in-line connector, but it can be modified to accommodate bulkhead mounting and an in-line "T" configuration. The internal contact orientation maintains the parallel plane geometry of the power cable conductors through the connector. This arrangement helps keep the power system inductance low. The prototype 20-kHz power connector has a design voltage drop of 0.375 V rms at rated current (68 A) and weighs approximately 1 lb. It has also been designed for compatibility with extravehicular activity. Several connectors will be installed in the Lewis space station test beds for component and system evaluation.

Lewis contact: Gregory V. Schmitz, (216) 433-5322
Headquarters program office: OSS

Remote Bus Isolators

The Leach Corporation has developed for NASA Lewis a family of 440-V, 20-kHz remote bus isolators (RBI's)—25, 50, and 100 A. The RBI's are metal contactors that are used for power bus reconfiguration. Under normal operating conditions they will not be switched under load. Testing at Lewis has shown that they may be switched when current is flowing, but this is not desirable. The RBI's will only accept on and off commands. They will supply to the data system the status (on or off), the bus current, the bus voltage, the sign of the volt-ampere product, and the last current reading when power was removed from the bus. The last current reading plus the sign of the volt-ampere product will be used for system failure analysis. The RBI's will be installed in the Lewis space station power system test bed for component and system evaluation tests.



Remote bus isolator

Lewis contact: Francis M. Haraburda, (216) 433–2325
Headquarters program office: OSS

Remote Power Controllers

Under contract to NASA Lewis the Leach Corporation has developed a family of 208-V rms, 20-kHz remote power controllers (RPC's)—5, 10, and 25 A. The RPC's are current-limiting switches that isolate the power distribution system from load faults. If a load faults, the RPC switches in a current-limiting reactance within 2 μsec, limits the fault to 300 percent of the current rating of the RPC, and removes the load at the end of the first half cycle of operation (25 μsec). The RPC's will accept on and off commands and current trip-point commands. They will supply to the data system the status (on or off), the load current, the load voltage, the sign of the volt-ampere product, and the last current reading before tripping. This last current reading will allow time for system failure

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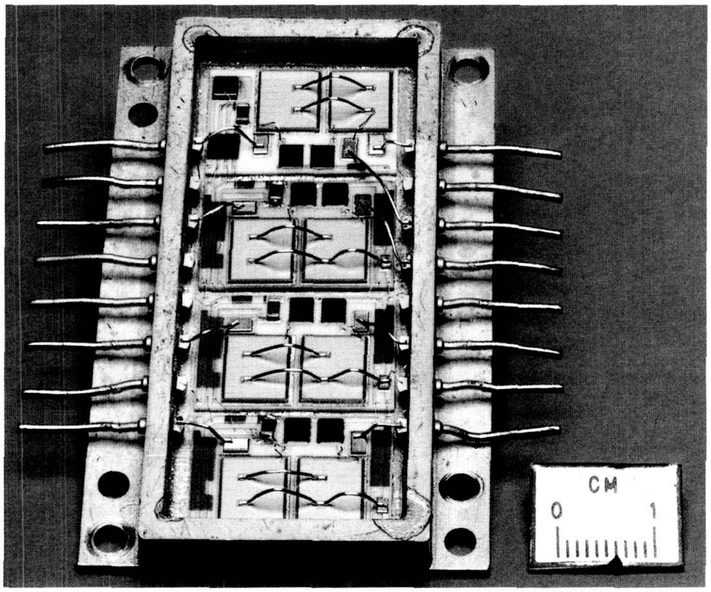
analysis while protecting the system from overload. The Leach RPC uses parallel field-effect transistors for the switching function and has a metal contact relay in series for dead heading the switch. The RPC's will be installed in the Lewis space station power system test bed for component and system evaluation tests.

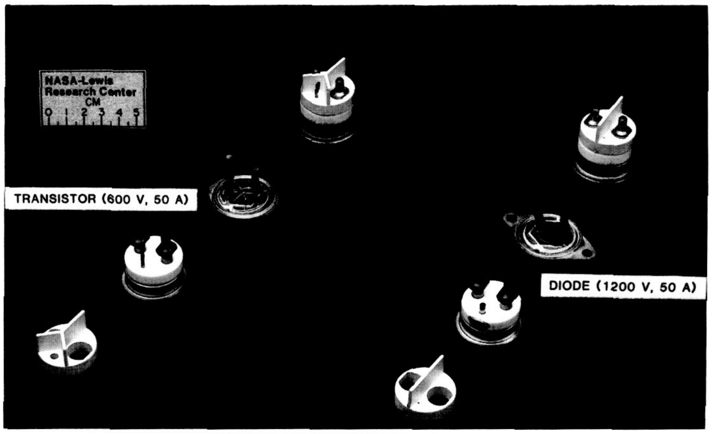
Lewis contact: Francis M. Haraburda, (216) 433–2325
Headquarters program office: OSS



208-V, 8-A field-effect transistor module

Power Semiconductor Package

Power Technology Components has developed for NASA Lewis a new high-power semiconductor package. This package has low inductance owing to the lead configuration and electrically isolates the power chip from the case. The package is hermetically sealed and has an internal coating of Parylene (Union Carbide Corp. trademark) for voltage breakdown protection if the hermetic seal fails. Among its advantages is the reduced area being driven by common mode voltages when it is applied in a bridge circuit. A smaller area minimizes the leakage currents coupled into the heat sinks. Both transistor (600 V, 50 A) and diode (1200 V, 50 A) packages were developed to the prototype stage.



Power semiconductor package (chip isolated from case)

The metal-oxide-semiconductor-controlled thyristor chip developed by the General Electric Company will be mounted in this package and then tested in various space station test bed circuits. Power Technology Components has marketed a commercial version without the Parylene coating as their "power mode" series.

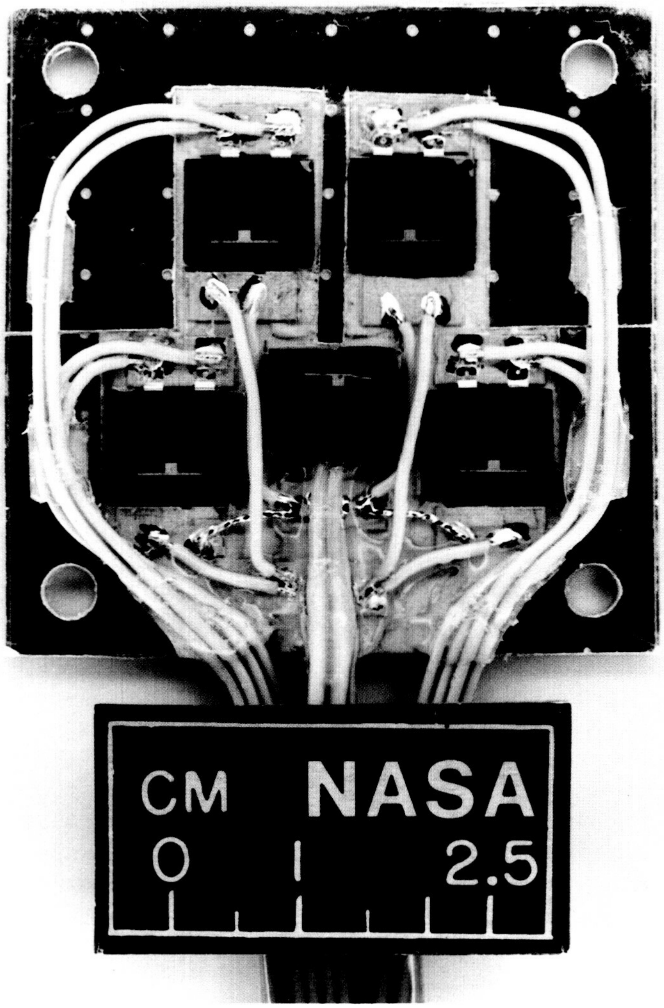
Lewis contact: Sam W. Hussey, (216) 433–8312
Headquarters program office: OSS

Power Generation

Flight Test of Indium Phosphide Solar Cell

Indium phosphide (InP) solar cells are excellent candidates for photovoltaic space power generation because their high-efficiency performance is coupled with significantly higher radiation tolerance than that of any other type of cell in use today. Development of InP cells has been under way for several years with impressive results. However, with the scarcity of spaceflight opportunities, InP cells had not demonstrated their performance under actual on-orbit conditions. The decision of the Naval Research Laboratory in 1986 to fly the third living plume shield (LIPS III) satellite has provided the first opportunity to obtain invaluable flight data on InP solar cells.

NASA Lewis assembled a module of four homojunction solar cells for flight on LIPS III, which was launched in late spring 1987 into a nearly circular, 1100-km orbit at an inclination of greater than 60°. The LIPS III satellite contains 142 solar cell experiments encompassing the widest possible variety of cell materials, designs, and optical configurations. This variety enables intercomparison of cell types and greatly enhances the value of the experiment.



Flight module of indium phosphide solar cell

Lewis contact: Dr. David J. Brinker, (216) 433-2236
Headquarters program office: OAST

Transforming Solar Cell Contact Formation From an Art to a Science

At present solar cell contact formation is more of an empirical art than a science. Properly sintered contacts are essential to ensure efficient operation of solar cells and other semiconductor devices. Good mechanical adhesion and good electrical contact require that the contact metallization be thermally treated after it has been deposited on the semiconductor surface. Although sintering conditions for solar cell rear contacts are not too critical, times and temperatures must be carefully chosen for the front contacts because of the proximity of the junction. Thermal treatment must be thorough enough to ensure good electrical contact but not so severe as to degrade the junction. This sensitive task is reduced to the state of trial and error because the mechanisms underlying the relevant metal-semiconductor interactions are complex and not fully understood.

A program directed at alleviating this situation through promoting understanding of the mechanisms involved in contact formation was therefore begun. It has produced some interesting and unexpected results. It has been determined, for example, that the metallurgical reactions that take place between all of the photovoltaically important semiconductors (i.e., silicon, gallium arsenide, and indium phosphide) and their contact metallizations are controlled not by conditions at the metal-semiconductor interface but by the condition of the free surface of the contact metal. More specifically, the reaction rates have been shown to depend upon the ability of the free surface of the metal to generate or annihilate (depending on the system) lattice vacancies.

The presence of lattice disorder at the metal surface due to a scratch or other mechanical damage, for instance, greatly increases the metal-semiconductor reaction rate. The vacancy generation rate is enhanced in regions of lattice disorder. On the other hand if the vacancy generation rate is reduced, the interaction rate can be significantly lowered. It has been shown that the application of an insulating layer such as SiO_2 or Ta_2O_5 on the surface of the contact metallization sharply reduces the vacancy generation rate and thus the metal-semiconductor reaction rate.

Another example of the sensitivity of the metal-semiconductor reaction rate to conditions at the metal surface is the significant increase in the reaction rate when heating occurs in vacuum rather than in a gaseous ambient. In a gaseous ambient environment the kinetic impact of ambient gas molecules on the metal surface inhibits the formation of vacancies. Operation in a vacuum environment removes the inhibiting effect of the impacting gas molecules and thus allows the reaction to proceed at a faster rate. This unexpected sensitivity to vacuum has serious implications for the use of radiation damage annealing in a space environment.

Having determined the factors controlling the reaction between the solar cell and its contact metallization, the way is now clear to devise means to control these potentially deleterious interactions.

Lewis contact: Victor G. Weizer, (216) 433–2230
Headquarters program office: OAST

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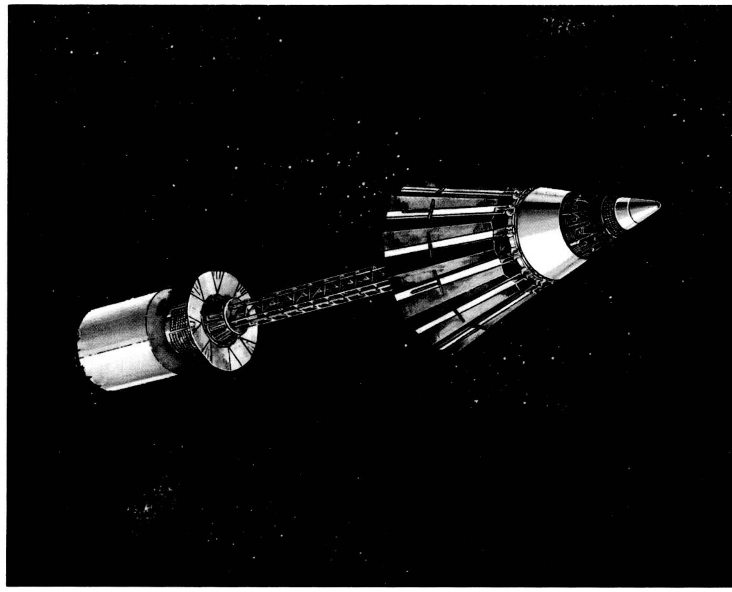
Studies of SP–100 Reactor Power System Applications



100-kW SP–100

Under NASA Headquarters sponsorship, NASA Lewis conducted preliminary feasibility studies of small reactor power systems for unmanned solar system exploration missions and manned planetary surface base missions. The purpose of these studies was to identify and assess the technology, safety, and performance issues associated with mission integration of reactor power systems. Unmanned solar system exploration studies were based on the use of the Mariner Mark II Cassini spacecraft and mission. Replacing the proposed Cassini radioisotope thermal generator (RTG) power supply with a 1-kW reactor power system was shown to be feasible from technology and safety perspectives. The additional reactor power system mass incurred a flight time penalty of 0.8 to 1.3 years but offered significant launch safety advantages. Both the Cassini RTG power supply and the chemical propulsion system that provides boost to interplanetary trajectory could be replaced with a 27-kW nuclear electric power and propulsion system without changing the flight time. At even higher power levels flight time could be shortened. In addition, electric propulsion utilizes the direct trajectory to the planets and hence eliminates all gravity-gradient-assist maneuvers typical of chemical propulsion and enlarges the available launch window. Upon arrival at its Saturn destination the reactor-powered Cassini spacecraft would also have significantly more power available for payload, substantially enhancing the science return on the mission.

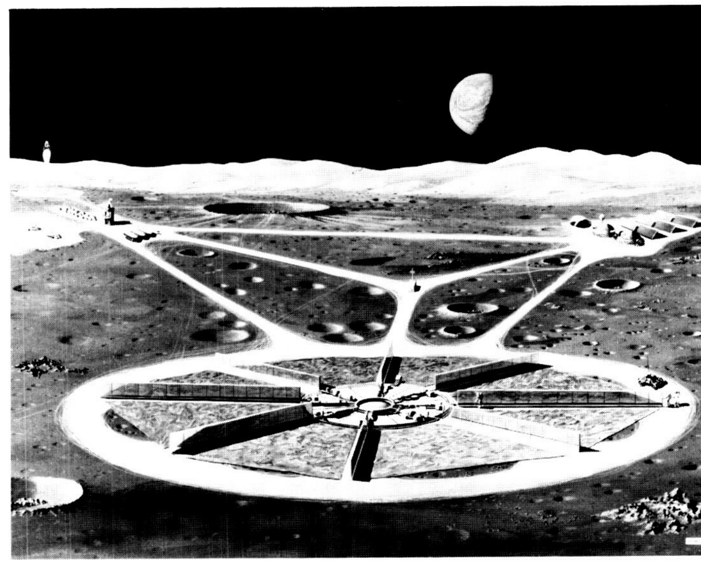
Mission studies for manned planetary surface bases indicate that a wide variety of reactor powerplant configurations is feasible for these evolutionary, growth-oriented mission applications. No technical or safety barriers were identified. Additionally, the use of indigenous planetary soil material for shielding people from the reactor radiation was shown to be an extremely viable, low-mass and low-cost option.

Under joint Department of Energy/Air Force Systems Command sponsorship, 14 space reactor power system concepts (5 to 40 kW) were evaluated and compared by an independent evaluation panel. The panel reviewed and assessed alternative space reactor power system concepts and compared them with scaled-down and derivative SP–100 concepts to determine whether an additional national reactor development program should be undertaken. Using criteria agreed to by the sponsoring agencies, the panel concluded that an additional full-scale reactor development program is not required. The successful development of SP–100 technology for missions in the middle to late 1990's will allow production of scaled-down SP–100 versions to meet orbital power needs in this range.

Lewis contact: Harvey S. Bloomfield, (216) 433–6131
Headquarters program office: OAST

SP–100 Reactor for Lunar-Base Powerplant

NASA Lewis has carried out a preliminary conceptual design study of a high-capacity lunar-base powerplant under the sponsorship of NASA Headquarters. The powerplant uses both solar photovoltaic and nuclear reactor power systems to meet life support and operational power requirements. The solar system consists of an amorphous silicon solar cell array combined with a regenerative H_2–O_2 fuel cell storage subsystem. This system can provide up to 100 kWe for initial outpost power as well as backup life support. Selection of power level depends on crew size. The nuclear reactor power system is constructed and installed during the initial outpost mission phase. It consists of a 2.5-MWt SP–100 reactor coupled to eight independent Stirling-cycle power conversion units. The reactor and the primary heat transport loop are located in a cylindrical excavation on the lunar soil, which provides the required radiation shielding. Eight Stirling engines, radiators, and power management and distribution subsystems are located on the lunar surface in a spoked wheel configuration. The nuclear power system is designed to generate 825 kWe with six Stirling engines in operation. Conceptual lunar-base layout configurations have been defined for typical load centers such as habitat and science laboratory modules, rover storage and charging, and materials processing for lunar mining operations.



Lunar-base powerplant

Lewis contact: Harvey S. Bloomfield, (216) 433–6131
Headquarters program office: OAST

R&D 100

Advanced Individual Pressure Vessel Nickel-Hydrogen Cell

The primary function of the advanced rechargeable individual pressure vessel (IPV) nickel-hydrogen cell is to provide electrical energy storage for long-term, low-Earth-orbit spacecraft missions. What is new in this cell design that is not incorporated in state-of-the-art nickel-hydrogen cells is (1) use of a modified electrolyte composition—26 percent rather than 31 percent potassium hydroxide (KOH) electrolyte, (2) use of a patented catalyzed wall wick, (3) use of serrated-edge separators to facilitate gaseous oxygen and hydrogen flow within the cell while still maintaining contact with the wall wick for electrolyte management, and (4) use of a floating stack rather than a fixed stack (state of the art) to accommodate nickel electrode expansion due to charge/discharge

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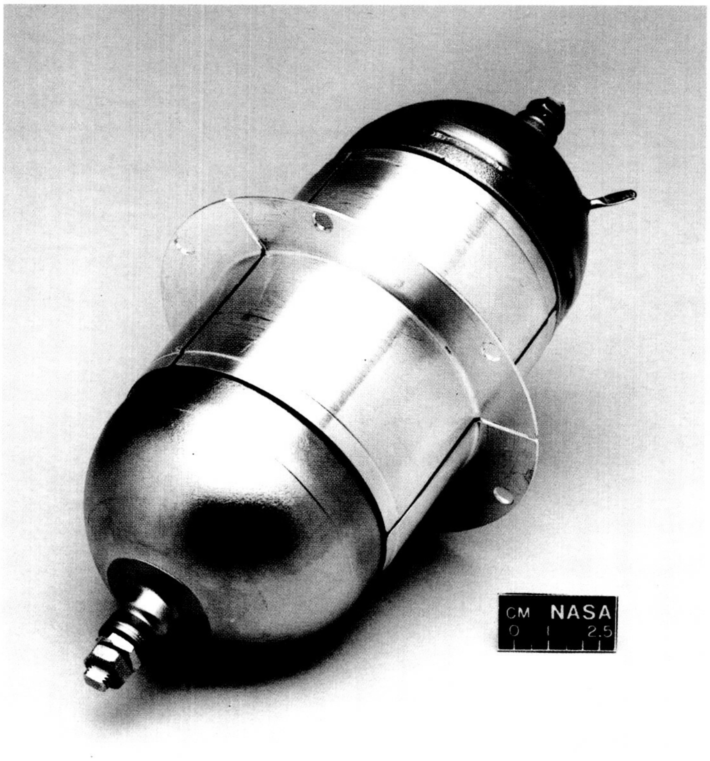
cycling. The significant improvements resulting from these innovations are extended charge/discharge cycle life; enhanced thermal, electrolyte, and oxygen management; and accommodation of nickel electrode expansion.

The modified electrolyte composition improved cycle life by greater than a factor of 10 over state-of-the-art cells. In a recent test (Hughes, under a NASA Lewis contract) the cycle life with 26 percent KOH electrolyte has been shown to be over 39,000 low-Earth-orbit cycles at 80-percent depth of discharge in contrast to 3500 cycles for state-of-the-art cells with 31 percent KOH. This breakthrough in cycle life conclusively shows viability and enables major low-Earth-orbit missions such as space station and space platforms.

The catalyzed wall wick improved thermal, electrolyte, and oxygen management. The oxygen generated at the end of charge is recombined chemically with hydrogen on the catalyzed pressure vessel wall wick, where the heat of recombination is much easier to remove. The cell average temperature at the end of charge is thus reduced by about 5 deg C over state-of-the-art cells, which cells recombine the oxygen on the catalyzed electrode surface in the stack. This lower operating temperature and reduced internal temperature gradients also enhance electrolyte management by reducing water vapor transfer. Damage to the hydrogen electrodes due to concentrated oxygen recombination is also eliminated by using the catalyzed wall wick. Oxygen management was further improved by using the serrated-edge separators to facilitate the flow of oxygen and hydrogen within the cell. Accommodation of nickel electrode expansion due to cycling was improved by using an expandable stack, which allows for a 30-percent increase in electrode thickness.



Individual pressure vessel nickel-hydrogen cell

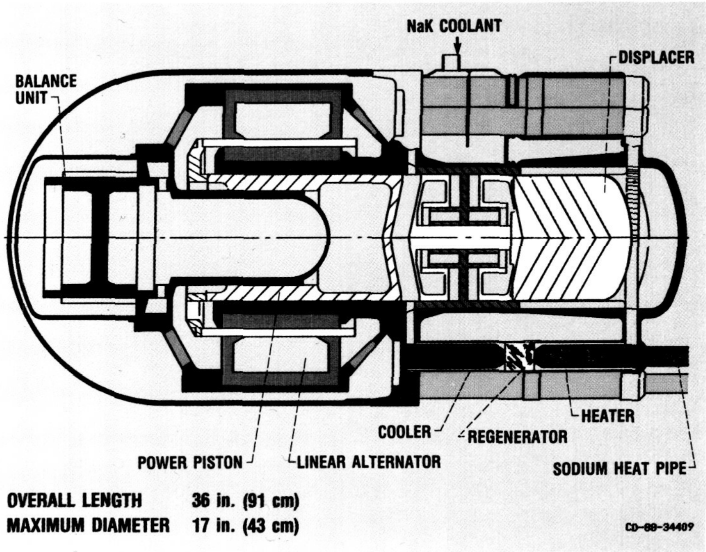
The principal application for the advanced nickel-hydrogen cell and battery is as the electrical energy storage portion of a space power system which requires a long, low-Earth-orbit cycle life (30,000 cycles, 5 years) at modest to deep depths of discharge (35 to 80 percent). This battery is the baseline energy storage system for the space station. The serrated separator feature of the advanced cell has been adopted by the Air Force. The advanced cell was also adopted by Ford Aerospace and Whittaker-Yardney Power Systems for a scaled-up 220 A-hr capacity nickel-hydrogen cell intended for high-power applications.

Research & Development magazine has selected the advanced IPV nickel-hydrogen cell to receive an R&D 100 Award as one of the 100 most significant technical developments of 1988.

Lewis contact: John J. Smithrick, (216) 433–5255
Headquarters program office: OAST

Advanced Stirling Space Engines

Recent advancements in key free-piston Stirling engine component technologies have provided the baseline data necessary for the design and fabrication of more advanced engines. A contract has been awarded to Mechanical Technology Inc. for the fabrication and testing of at least two advanced 25-kW Stirling space engines. The objective is to demonstrate full-scale experimental engines by the end of 1992. These engines will be operated at 1050 K and serve as low-temperature preprototypes of a 1300 K engine.



Early conceptual design of 1050 K Stirling space engine

The recent component advancements, carried out on the existing two 12.5-kW space power research (SPR) engines, have provided data that are directly applicable to the design of the Stirling space engines. The successful and timely completion of the following key technologies provided the strong technology base needed to begin the Stirling Space Engine Program.

A hydrodynamic gas bearing was successfully demonstrated. This bearing is a replacement for the hydrostatic gas bearing used to support the power piston of the SPR engine. Since the hydrodynamic bearing causes less power drain on the engine than the hydrostatic bearing, nearly a 10 percent increase in engine output power is expected by this replacement.

Linear alternator dynamometer tests have shown that eddy current power losses can be reduced significantly by using nonmagnetic alternator structural materials. Eddy current losses were the principal loss that reduced the efficiency of the SPR engine's alternator from the design value of 93 percent to 70 percent. These tests provided the design knowledge needed to fully recover the efficiency of the SPR engine's alternator.

Design of a 1050 K heat-pipe heater head for the SPR engine has been completed. This heater head contains 45 heat pipes, a main simplification over the original SPR engine's 1600-tube heater head. Overall performance and engine reliability should improve. The superior heat transfer ability of heat pipes provides a more uniform temperature input to the engine and allows higher temperature operation and greater engine efficiency.

Lewis contact: Donald L. Alger, (216) 433–6118
Headquarters program office: OAST

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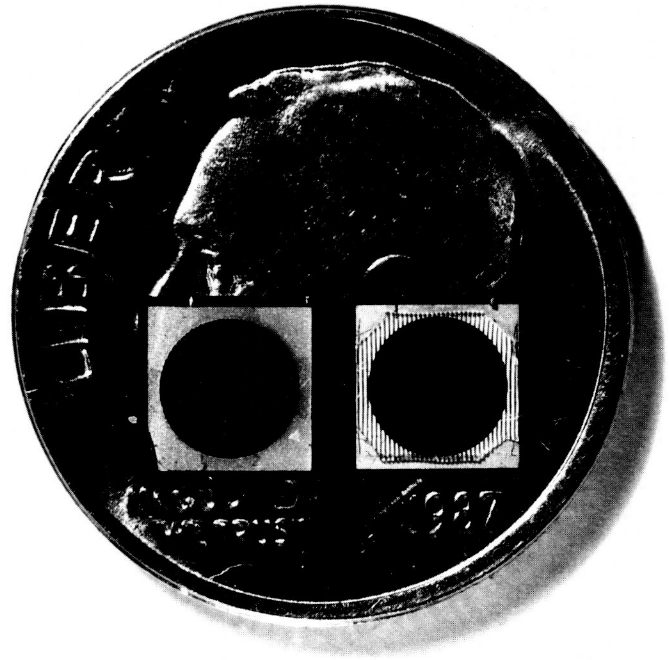
High-Efficiency Gallium Arsenide Concentrator Cell With Simplified Grids and Grooved Coverglass

The advantages of concentrator solar cells for space use include higher cell operating efficiency; a built-in radiation hardness due to the optical system; and an economical use (much smaller cell area required) of expensive high-performance cells. One drawback has been the requirement of a complicated top grid pattern that covers 10 to 15 percent of the cell. Cells operating under concentrated sunlight have a higher current density than normal cells and hence must have greater grid coverage to keep internal resistance losses low. Under an Small Business Innovation Research contract managed by NASA Lewis, the Entech Corp. has further developed a grooved coverglass concept that eliminates the current loss to the top grid coverage area.



Concentrator solar cells

The coverglass has a grooved pattern on the underside that matches the top grid pattern. The grooved coverglass operates by refracting incident sunlight away from the grid lines, thus removing the blockage penalty of the grid and increasing the cell output. A secondary advantage is the relaxed constraints on the grid geometry. Grids presently are designed with a radial spoke pattern involving hundreds of very thin lines in order to optimize cell performance. Since the grooved coverglass removes the constraint of minimum grid blockage, the lines are fewer and thicker and oriented in a simple parallel-line design. The grooved coverglasses can be made from either acrylic plastics or space-qualified glasses and are applied with space-qualified adhesives.

Concentrator solar cells with this coverglass have achieved the highest solar cell efficiencies measured under the outer space spectrum. Entech obtained gallium arsenide (GaAs) concentrator cells (whose development was partially funded by Lewis) from Varian Association and applied the grooved coverglasses. Lewis measured cell performance both before and after application of the coverglasses. The results with the grooved coverglass gave an efficiency above 24 percent at 25 °C and 100 times air mass zero. The increase in current was about 12 percent. This enhancement, which directly increases cell performance, can be transferred to higher technology cells such as multijunction cells with the same percentage improvement.

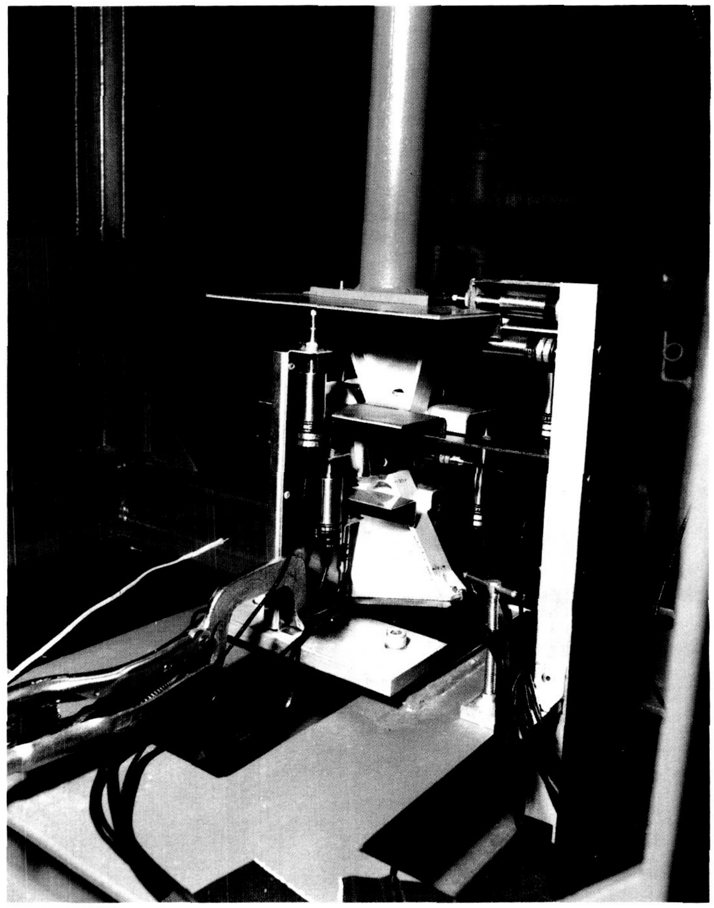
Lewis contact: Michael F. Piszczor, Jr., (216) 433–3357
Fund source: SBIR

Stiffness Test of Solar Dynamic Concentrator Latch

The solar dynamic concentrator is a large flight-weight mirror used to concentrate solar energy for driving a heat engine. The heat engine will be used to generate electric power for the space station. The solar concentrator consists of 19 hexagonal frames linked together with latches. The latch geometry is set to map the hexagonal frames onto the spherical surface. Since accurate analytical modeling of the latch stiffness is difficult because of the potential nonlinearities, it was decided to perform a test verification.

NASA Lewis currently plans to test each of the four latch configurations in the primary load direction and in two orthogonal directions. The test loads are applied with a load fixture in the form of an enforced displacement. The latch load is measured with a load cell, and the corresponding latch displacements are measured with linear variable displacement transducers. The data are recorded on a Fluke multichannel data recorder and subsequently processed with Lotus software.

To date, the primary axis of the type I latch has been successfully tested. Preliminary results indicate that the type I latch is linear in the range of the estimated orbit loads.



Solar dynamic concentrator latch testing

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Lewis contact: Joseph M. Roche, (216) 433-2575
Headquarters program office: OSS

Thermal Management

Thermal Management for Space Power Conversion Systems

Thermodynamic power conversion systems can only convert a portion of the cycle input thermal energy, or heat, to useful work (i.e., electrical energy). The remainder of the cycle input heat must be rejected to a low-temperature sink that is below the lowest temperature of the cycle. For closed space power systems with continuous recirculation of working fluid, heat rejection has to be by radiative heat transfer from extended surfaces of space radiators to an equivalent space sink temperature. This equivalent sink temperature varies with radiator configuration and orientation relative to the Sun, and it may range from 200 to 270 K in low Earth orbit.

Since large-surface-area space radiators represent a major portion of the overall power conversion system mass, intense analytical and experimental work is being conducted to develop lightweight radiator components and to tailor cycle operating conditions so that overall system mass is minimized. Radiators for space operation are required to survive a variety of natural hazards, including micrometeoroids and space debris, and this represents a significant design constraint.

Radiator concepts being studied at NASA Lewis include pumped-loop designs, concepts based on heat pipes that use a variety of working fluids and containment materials, and advanced concepts such as liquid sheet, moving belt, and Curie point radiators. These advanced concepts have the potential of significantly reducing space radiator mass and hence total payload mass to be launched to orbit.

Lewis contacts: Dr. Marvin Warshay, (216)433-6126; Albert J. Juhasz, (216)433-6134
Headquarters program office: OAST

Advanced Low-Mass, Liquid-Sheet Radiator Concept for Space

The only means of eliminating waste heat in space is by radiation. Present radiator designs, although effective, are relatively massive. As the power requirements of future satellites rise, so will their mass. It is projected that in certain cases the radiator will be the heaviest component of a space power system.

One way of significantly reducing radiator mass is to eliminate the walls that contain the working fluid. Ease of deployment and near immunity to micrometeoroid damage are two other important advantages of an external-flow radiator. The potential disadvantages posed by the direct exposure to the space vacuum and radiation field can be dealt with by using existing heavily fluorinated organic or metal liquids, both of which have vapor pressures $\leq 10^{-8}$ torr and are highly radiation resistant.

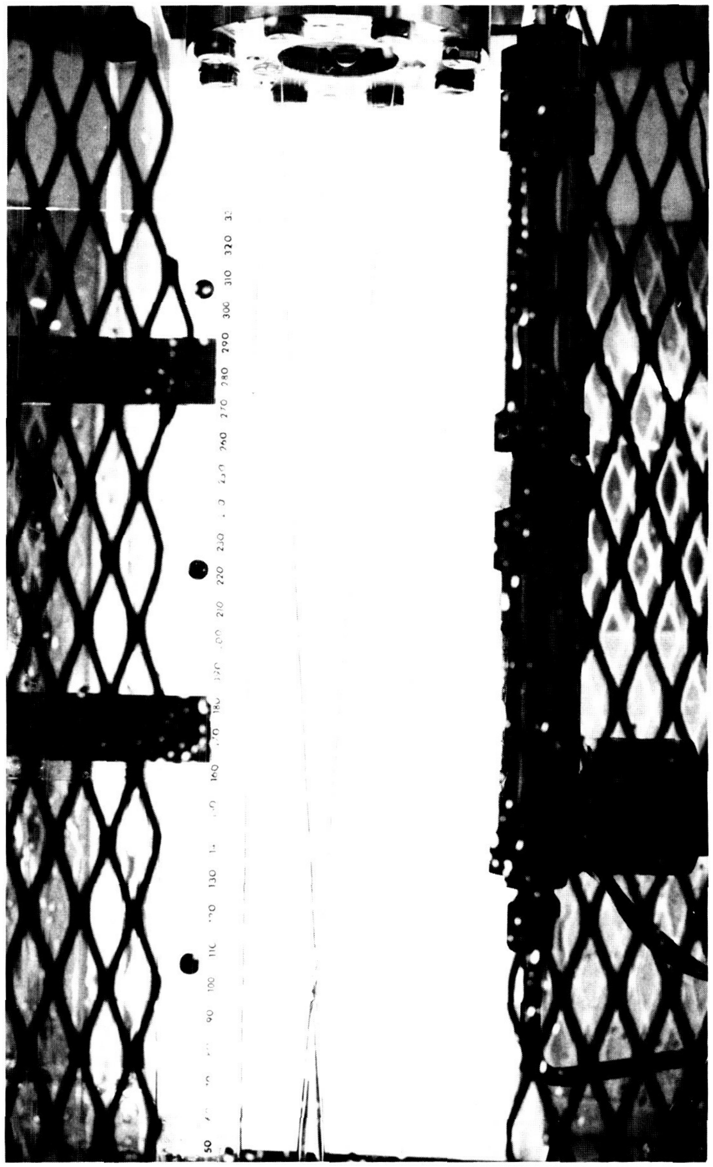
To date, the liquid droplet radiator and the liquid belt radiator have received the most research attention. As part of the NASA Lewis thermal management program a new external-flow radiator, the liquid sheet radiator, is being investigated. The liquid sheet radiator uses a thin (~ 100 μm) liquid sheet as the radiating surface.

A unique characteristic of thin-sheet flow is that surface tension causes the flow to coalesce in a triangular form. The surface tension causes cylinders to form at the edges of the sheet that grow in diameter in the flow direction. As they grow, the sheet width decreases in order to satisfy the conservation of mass. Eventually the cylinders meet and coalesce to a single cylindrical cross section, which is ideal for fluid collection.

Calculations based on a simple model for the sheet flow predict a *linear variation*, with sheet velocity, of the ratio of sheet length to initial sheet width. Experiments with silicone diffusion pump oils at vacuum conditions and with various width slits confirm this analytical result. Sheet flow widths of about 1 m are desired for a practical liquid sheet radiator. Experiments are being conducted to determine how the sheet flow scales with increasing width.

A radiative heat transfer analysis predicts that the specific power (ratio of radiated power to sheet mass) of a continuous sheet is nearly the same as the calculated specific power of a liquid droplet sheet. However, the liquid sheet radiator's generator and collector are *simpler in design and fabrication* than those of a liquid droplet radiator. Therefore the liquid sheet radiator is expected to have higher total system specific power.

Lewis contact: Donald L. Chubb, (216) 433–2242
Headquarters program office: OAST



Sheet flow of Dow-Corning 704 oil in vacuum

Facilities

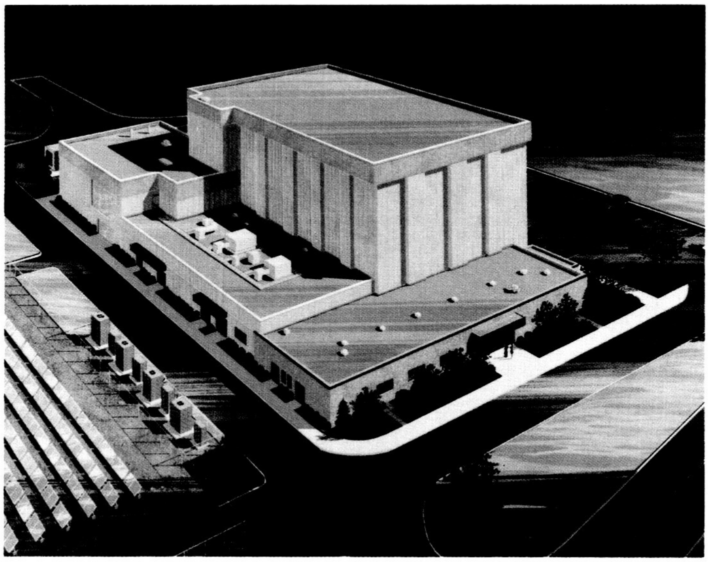
New Power Systems Facility Constructed to Test Space Station's Electrical Power System

NASA Lewis has been assigned responsibility for the design, construction, prelaunch checkout, launch, and on-orbit operation of the space station electrical power system. This responsibility includes the development and integration of all the components and subsystems for the generation, storage, management, and distribution of electrical power to the user. The Power Systems Facility has been constructed to provide Lewis with the capability of meeting this responsibility.

PSF is Lewis' newest facility, built at a cost of $6.2 million. It provides facilities for a wide range of space station electrical power system testing, including tests on the power management and distribution system and its components, tests of nickel-hydrogen batteries for energy storage, and optical alignment tests of a solar concentrator mirror. PSF will also be able to monitor on-line the performance of the orbiting space station power system and to simulate, for analysis and resolution on the ground, any anomalies experienced in space.

The building has several unique features, including the main test area, two explosion-proof test cells, and the controls and data laboratory. The main test area is an 8300-ft^2 high bay area with 55 ft of clearance below the 10-ton crane. This area can operate as a class 100,000 clean room. In each of the explosion-proof test cells the interior walls and ceiling are constructed of

Power Systems Facility



12-in.-thick reinforced concrete. The exterior wall is designed as a blowout panel that will act as a pressure release in case of an explosion. The controls and data laboratory contains computers that will simulate the electrical power system control and other space station controls. These simulators will interact with power system hardware being tested in the main test area.

The adjacent solar array field is an array of 960 silicon solar cell modules. The maximum array power is 30 kW at 160 V. The power from the solar array field will be used for testing power system hardware and subsystems in PSF.

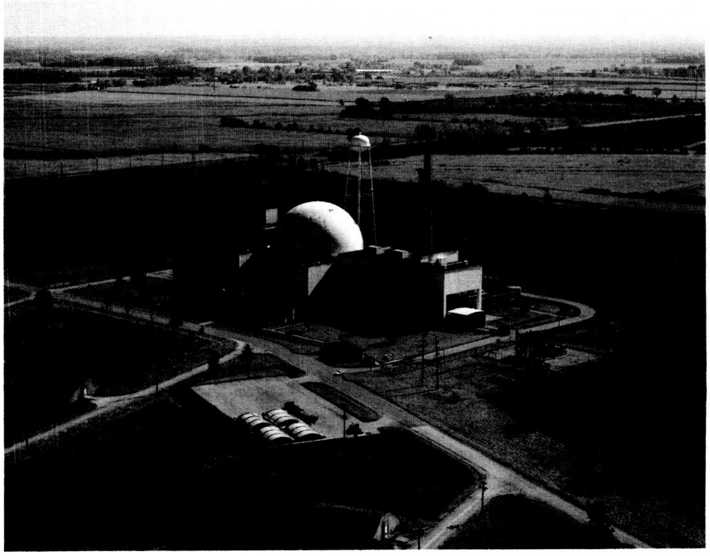
Lewis contacts: Paul Weisenbach, (216) 433–5459; Gordon D. Mackay, (216) 433–2715
Headquarters program office: OSS

Space Power Facility Restored

The restoration of the Space Power Facility (SPF) at Plum Brook Station was completed by NASA Lewis this year. The SPF provides an environment that simulates space thermal vacuum conditions. It will be used for a variety of future space programs.

The 100-ft-diameter by 121-ft-high vacuum chamber is the largest in the world. The vacuum chamber features an aluminum inner wall enclosed by a 6-ft-thick concrete wall that provides the necessary structural strength and acts as a containment vessel for nuclear tests. The vacuum chamber can be evacuated to 10^{-6} torr in about 8 hr. Inside the vacuum chamber is a 40-ft-diameter liquid-nitrogen-cooled cold wall capable of surface temperatures from -60 to -300 °F. The cold wall is constructed in four sections and can be used in a variety of positions. In addition, the facility can provide a 400-kW solar simulator for tests that require it.

Tests scheduled for the SPF are the Department of Defense SPEAR II, a Centaur shroud separation test for General Dynamics in support of the commercialization of the space program, and a photovoltaic power module test for the space station. Before its shutdown in 1975 the SPF was used for shroud separation tests, Brayton cycle tests, and cloud physics tests. From 1976 to 1986, the Department of Energy with the AiResearch Manufacturing Company leased the facility for centrifuge manufacturing. During that time extensive modifications were made to the test chamber and its associated equipment. The facility has been restored to its original configuration during the last 2 years.



Plum Brook Space Power Facility

Lewis contacts: Thorvald Brink, (216) 433-6368; William Pack, (216) 433-5343; Robert Kozar, (419) 625-1123

Power Management and Distribution System Test Bed

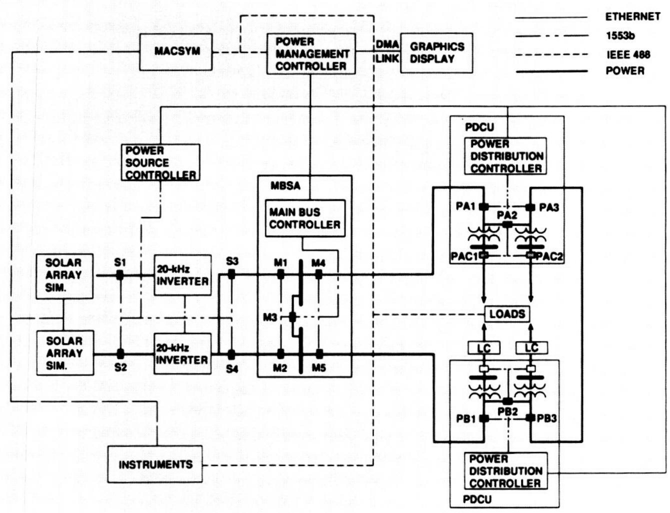
Lewis has assembled a power management and distribution system test bed to support the design and development of the space station electrical power system by addressing system design issues such as system protection, control, and load management. The test bed incorporates components that are functionally similar to the orbital replacement units expected for the space station. These units are the inverters, used to parallel the source inverters, and a power distribution and control unit (PDCU), used to control and monitor the loads.

The test bed also contains a distributed, hierarchial control system consisting of a power management controller, a power source controller, a main bus switching assembly controller, and two PDCU controllers. Processor-to-processor communication is through an Ethernet data bus, and processor communication with

lower level power components is through a 1553b data bus. All software is in the Ada programming language.

The source inverters and load receivers were developed by TRW. The main bus switching assembly, the power distribution and control unit, and the controllers were developed by Rockwell-Rocketdyne and Westinghouse.

Lewis contact: Raymond F. Beach, (216) 433–5320
Headquarters program office: OSS



Schematic of power management and distribution test bed

Modern Software Engineering

Lewis has installed five workstations for the software support environment (SSE). The SSE is being developed by Lockheed Missiles and Space Company, Inc. It will be used for software management, development, acquisition, integration, testing, and maintenance of all the Space Station Program operational software. The workstations at Lewis consist of two IBM PS/2's, one Mackintosh II, and two Apollos. All the workstations are networked and tied to the SSE Development Facility at the NASA Johnson Space Center through the program support communications network.

The software tools in the SSE will be integrated to provide Lewis and its space station prime contractor, Rocketdyne Division of Rockwell International, with a modern software engineering environment. This integrated capability will allow tracing from the software requirements to the actual Ada code that is generated. Use of this environment by all participants of the Space Station Program will facilitate integration of all the flight software.

Lewis contact: Carl J. Daniele, (216) 433–5325
Headquarters program office: OSS

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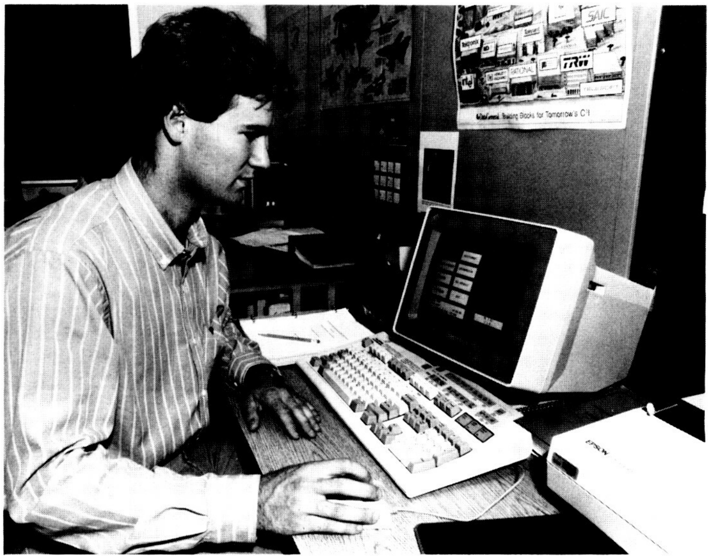

Software engineering workstation

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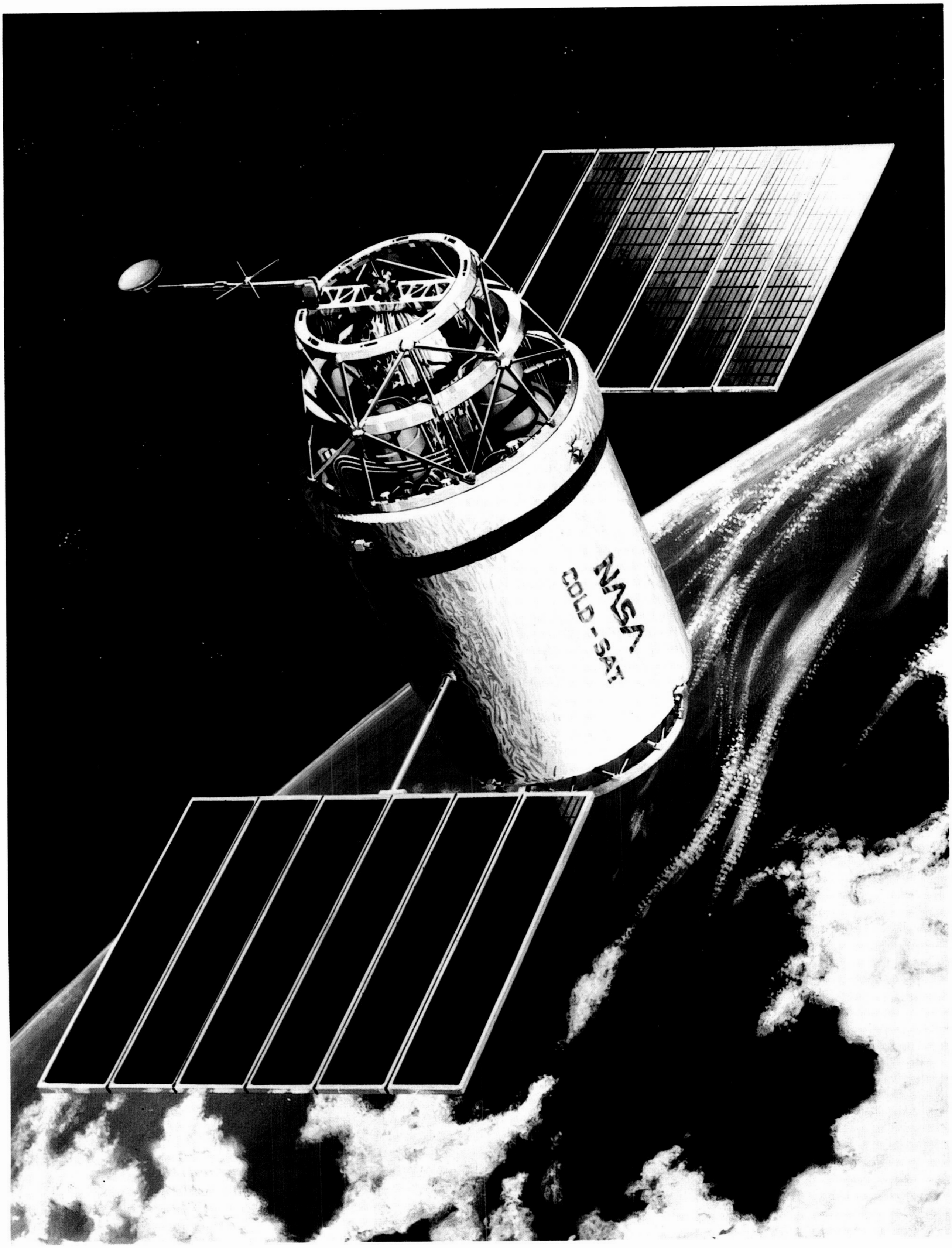

Space Science/ Applications

Strategic Objectives

- To achieve a leadership position in the technologies associated with the in-space management of cryogenic fluids.
- To seek opportunities to vertically integrate cryogenic fluid technology by capturing a role in developing the subsystems for an on-orbit fuel depot.
- To be the principal NASA center for in-space microgravity science and technology experiments in power, propulsion, materials, combustion, fluid physics, structures, and electronics/communications.
- To successfully complete the Advanced Communications Technology Satellite Project to keep the U.S. preeminent in the communications industry.
- To be the NASA center responsible for the development of any future Centaur-derived upper stages and to remain a principal NASA manager of unmanned launch vehicles.

Programs

Emmy Award Communications Technology Satellite

The National Academy of Television Arts and Sciences presented the Emmy to NASA for developing technology used in the Communications Technology Satellite (CTS). This outstanding achievement in television engineering ultimately improved television broadcasting throughout the world.

Launched in 1976, the CTS was the first communications satellite to incorporate a high-efficiency, high-powered transmitting tube developed at Lewis. The tube made it possible for the CTS to operate at power levels 10 to 20 times higher than those used at the time and in a frequency band, the Ku band, newly allocated to broadcast satellites. This higher broadcast capability made it possible to use much smaller and far less expensive ground receiving equipment than ever before. It also enabled transmission to remote areas where terrestrial communications are not highly developed.

Many domestic and foreign communications satellites in operation today are using the technology first demonstrated by the CTS. The CTS transmitter was turned off in October 1979 after more than 3 years of successful experimentation.

Emmy

Lewis contact: Godfrey Anzic, (216) 433–3570
Headquarters program office: OSSA

Advanced Communications Technology Satellite

The year 1988 was one of tremendous change for the Advanced Communications Technology Satellite (ACTS) Program. Responding to congressional direction to "cap" the total program costs, NASA restructured the entire program and took a more proactive management role in its contractual relationships while continuing to make great strides toward achieving its new launch readiness date of May 1992.

ACTS spacecraft deployed from space shuttle (artist's concept)

Under the restructuring General Electric's Astro-Space Division, the ACTS prime contractor, assumed responsibility for building the multibeam communications package, formerly in development by TRW. This major shift in responsibilities was coupled with NASA's assumption of the management role for the ground segment from GE Astro. COMSAT Laboratories continues to build the ground segment portion of the contract under this restructuring. New delivery dates, which coincide with the 18-month stretch in the program, have been agreed to, and the contractors' replanning activities are under way. Negotiations with both contractors to implement this program reorganization culminated in September with the signing by all parties of a tripartite agreement.

ACTS development, although initially slowed by the restructuring process, gathered momentum in 1988. GE Astro completed the critical design review of the spacecraft bus in May. Two weeks later, GE Astro presented to NASA its plan for the development and manufacture of the multibeam antenna and the communications electronics package. This crucial review not only reaffirmed NASA's confidence in GE Astro's ability to build those major technology systems, but it also signaled the shift from programmatic concerns and a return to design and development issues. COMSAT, at the same time, completed the critical design review of the radio-frequency terminal subsystem.

The last quarter of 1988 begins a new phase of the ACTS Program. Major technology subcontractors will start to deliver engineering and flight model components of the multibeam communications package to GE Astro. This sets into motion the assembly and test activities of the complete engineering model communications electronics package, a major program milestone. The completion of the ACTS system critical design review, planned for the fall of 1989, will mark the start of the manufacturing process for the spacecraft bus and multibeam communications package components at GE Astro.

It has been a year of great change for the ACTS Program. The changes, however, bring a sense of accomplishment in the past and greater stability for the program in the future.

Lewis contact: Thomas H. St. Onge, (216) 433-3557
Headquarters program office: OSSA

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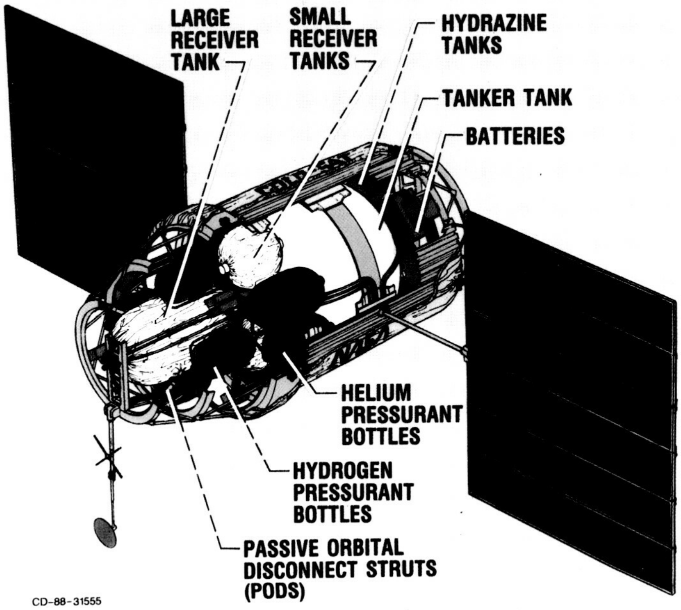
Cryogenic Fluid Management in Space

Future NASA and Department of Defense mission models include spacecraft that will be carried into orbit without cryogenic fluids in order to minimize lift-off weight and reduce launch pad thermal performance requirements. The cryogenic fluids will be separately transported to orbit and transferred to the spacecraft in the low-gravity environment of space. Other applications require the periodic resupply of space experiments, satellites, and space station subsystems in space to extend their useful lives. Cryogenic fluid management is an important part of the technology data base that must be developed in order to perform these future missions. The Cryogenic Fluids Technology Office has undertaken a program to develop the technologies essential for efficiently managing subcritical cryogenic fluids in the low gravity of space. A technology development spacecraft, COLD-SAT, has been proposed to perform cryogenic fluid management experiments after being launched into a low Earth orbit on an expendable launch vehicle. COLD-SAT will be designed for a 6- to 24-month life in orbit.



COLD-SAT spacecraft

During fiscal 1988 three parallel COLD-SAT feasibility studies were awarded to Ball Aerospace/ McDonnell Douglas/Boeing, Martin Marietta, and General Dynamics/ Ford Aerospace. These studies will provide system concept development; experiment, spacecraft, and system analysis; conceptual and preliminary COLD-SAT designs; mission design, establishing an overall development plan; and cost estimates for the COLD-SAT project. The studies will last 24 months and will provide information necessary to seek a new start in fiscal 1992.

A series of cryogenic fluid management experiments onboard the free-flying COLD-SAT spacecraft have been identified by the Cryogenic Fluids Technology Office. Broad technology areas include liquid storage, storing tanks of cryogens in space subcritically for a few hours to several years while minimizing boiloff and controlling tank pressure; liquid supply, delivering single-phase liquid from the storage tank to an end user; and liquid transfer, transferring liquid from a storage tank to a receiver tank under near weightless conditions while minimizing liquid losses and controlling the receiver tank pressure. Also of interest are the performance of advanced instrumentation such as leak detectors, flowmeters, and quantity gages and fluid handling problems such as liquid sloshing and tank venting and dumping.

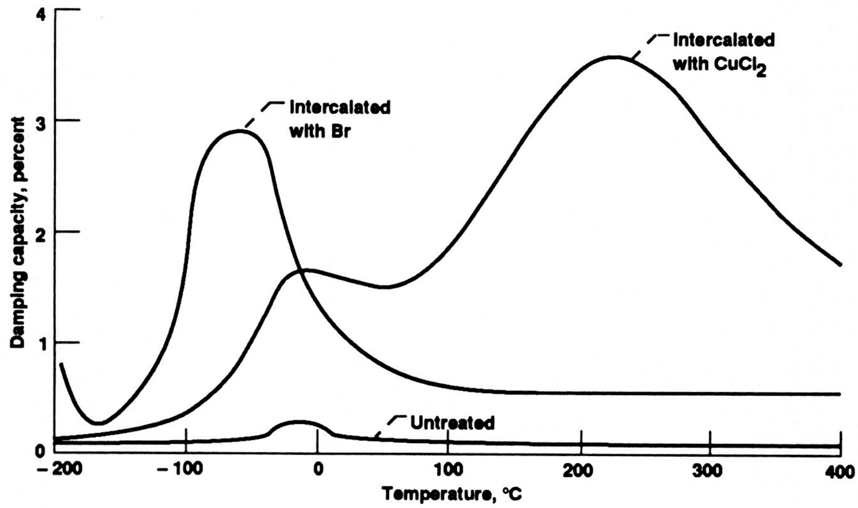
Individual experiments are planned to investigate the fluid physics and thermodynamics important in the processes associated with these technologies. The data obtained are to be compared with analytical models currently being developed. The established data base and the validated models will provide system designers with the tools necessary to configure future operational systems in orbit.

Lewis contact: Eugene P. Symons, (216) 433-2853
Headquarters program office: OAST

Research & Technology

Materials

High-Damping Graphite Fibers



Damping of P–100 graphite fibers

Lightweight structural materials with high internal damping could significantly improve the performance of high-precision space structures. With this passive source of vibration control, operational requirements such as precise pointing, rapid slewing, and extreme dimensional stability could be achieved with less need for active damping controls. Active controls have inherent weight and complexity penalties and do not perform well at high frequencies. For advanced precision spacecraft the prime structural material candidates are metal and glass composites reinforced by high-modulus, pitch-derived graphite fibers. These fibers are desirable not only because of their high stiffness, but also because of their negative axial thermal expansion at the low temperatures of the space environment. Since over 80 percent of the composite damping will be provided by the stiff graphite fibers, the need thus exists for measuring and improving the damping of these fibers.

To address this need, NASA Lewis recently conducted a study to measure the damping of as-fabricated and intercalated P–100 graphite fibers. These measurements were made with a fiber test rig developed at Lewis in which a single fine-diameter fiber is vibrated in flexure at audio frequencies in the temperature range −200 to 800 °C. Damping capacity results for untreated, as-fabricated fibers and for intercalated P–100 fibers are shown at temperatures from −200 to 400 °C and at frequencies near 400 Hz. Damping capacity is a measure of the percentage of mechanical energy lost to heat per cycle of vibration.

The data reveal very low damping for the untreated fiber but at least an order of magnitude increase in damping over a wide temperature range for those fibers intercalated with bromine or copper chloride. Of special interest is the large damping peak near −50 °C exhibited by the fibers intercalated with bromine. This peak not only occurred between −200 and 200 °C, the use temperature range for spacecraft, but also displaced a maximum damping capacity that is approaching a damping level beneficial to precision spacecraft. Indeed, since these data were obtained with no optimization of intercalants, it follows that significant damping improvements are possible with pitch-derived graphite fibers. These improvements should also be manifested in the damping of their structural composites, provided that inherent fiber damping mechanisms can be retained during composite fabrication and application.

Bibliography

DiCarlo, J.A.; and Williams, W.: Dynamic Modulus and Damping of Boron, Silicon Carbide, and Alumina Fibers. Ceram. Eng. Sci. Proc., vol. 1, no. 7–8B, July-Aug. 1980, pp. 671–692.

Lesieutre, G.A.; Eckel, A.J.; and DiCarlo, J.A.: Temperature-Dependent Damping of Some Commercial Graphite Fibers. Ceram. Eng. Sci. Proc., vol. 9, no. 7–8, July-Aug. 1988.

Lewis contact: Dr. James A. DiCarlo, (216) 433–5514

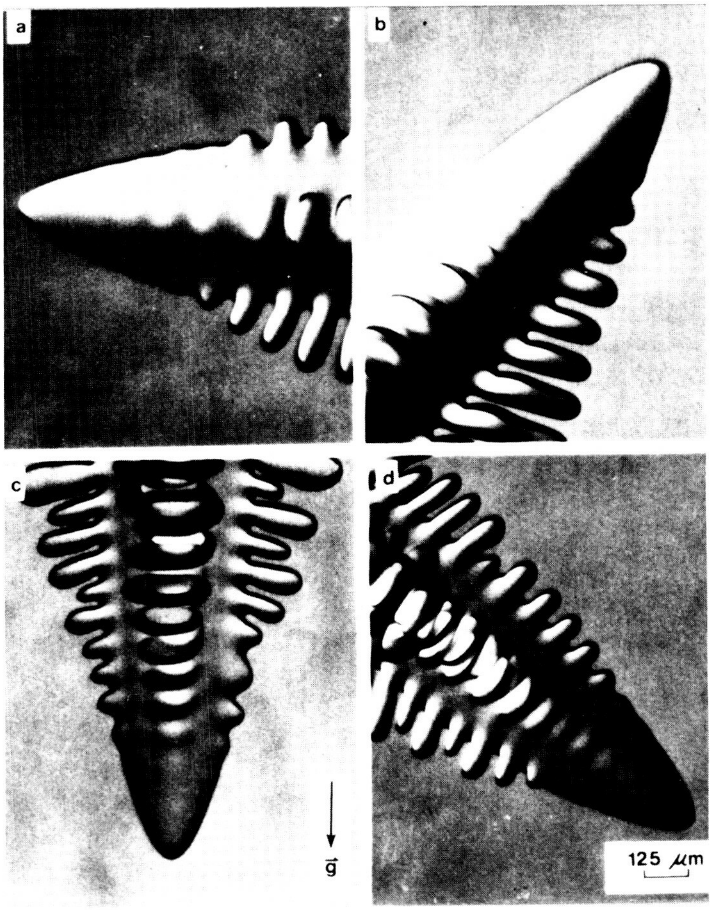
Headquarters program office: OAST

Dendritic Solidification Onboard Space Shuttle

The isothermal dendritic growth experiment (IDGE), to be conducted onboard the space shuttle, will test fundamental theories that describe dendritic freezing of liquid metals on Earth. Virtually all industrial alloys freeze by a dendritic process. Consequently the results should lead to improvement of Earth-based industrial processes used to produce steel, aluminum, superalloys, and other useful alloys. Rensselaer Polytechnic Institute scientists proposed the experiment to NASA. Lewis staff members then designed the spaceflight apparatus, which is being fabricated and tested at Lewis.

Specifically the IDGE will test theories that predict metal dendrite growth velocity, tip radii, and side branch spacings as functions of metal physical properties and liquid metal supercooling. Moreover, IDGE is designed to acquire data needed to correct the theories should they prove flawed. Experimentation on Earth has been ineffective because gravitationally driven convective mixing in liquid metal overshadows diffusional mixing. Experimentation in the microgravity of space will allow theorists to separate and understand gravitational and convective effects.

A unique shuttle-carried apparatus will automatically photograph dendritic freezing in succinonitrile (a transparent crystalline plastic material that has a crystal structure similar to that of iron). The apparatus must control temperature accurately to within 0.002 deg C; it must photographically resolve dendrites with tips smaller than a needle point (25 μm); it must measure microgravitational accelerations; and it must communicate data and slow-scan television images to Earth.



Succinonitrile dendrites in true growth orientation with respect to gravity. Change in geometry at different orientations is probably caused by temperature asymmetries induced by convective mixing.

Bibliography

Glicksman, M.E., et al.: Isothermal Dendritic Growth—A Proposed Microgravity Experiment. Metallurgical Transactions A, vol. 19A, Aug. 1988, pp. 1945–1953.

Lewis contact: Edward A. Winsa, (216) 433-2861
Headquarters program office: OSSA

Microgravity

Microstructural Analysis Confirms Modeling Results for Self-Propagating High-Temperature Synthesis

Self-propagating high-temperature synthesis (SHS) has attracted a great deal of attention in the last few years because of the success attributed to Soviet scientists. American workers have proposed SHS as a method for everything from synthesizing powder for structural ceramics to preparing superconductors. With an eye

toward NASA's possible future interests in this area, NASA Lewis joined with the Los Alamos National Laboratories (LANL) in a program to determine whether gravity would significantly affect the SHS process. LANL's efforts to model the process were supported by microstructural analysis at Lewis. It was argued that gravitational effects might measurably alter the combustion rate of SHS. Modeling indicated that spreading and wetting forces will mask any gravity effects. The spreading and wetting contribution was expected to exceed the gravitational effects by one or two orders of magnitude.

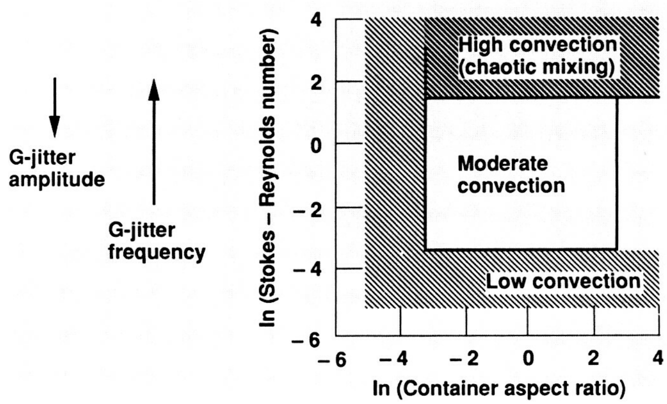
Although the model suggests that the kinetics of the SHS process are unchanged by gravity, it also suggests that the resultant microstructure will be affected by gravity. Nickel-aluminum specimens ignited in two different ways to simulate gravity were examined. Half of the specimens were ignited at the bottom so that the combustion reaction propagated upward. The other half of the specimens were ignited at the top so that the combustion reaction propagated downward. Both the modeling and the actual microstructural analysis were in agreement. Specimens burned in an upward direction have a much coarser pore structure than those specimens burned downward. Thus one may reasonably expect that specimens produced in low-gravity conditions will have finer pores than those produced on Earth.

Lewis contact: Janet B. Hurst, (216) 433-3286
Headquarters program office, OSSA

Convective Mixing of Two Fluids Under Microgravity Environment

For proper design of liquid-liquid experiments under a microgravity environment, it is important to quantify the level of convective mixing. A flow pattern map based on numerical results and quantifying the level of convection due to g-jitter can be used as a guide for designing proper microgravity experiments inside a space shuttle environment. It also has applications to mixing phenomena occurring during opposite-oriented diffusion growth, a method used for solution crystal growth.

The effects on fluid mixing of both steady gravitational field (for ground-based experiments) and g-jitter (for shuttle applications) were investigated both numerically and analytically. The numerical results have shown good qualitative agreement with ground-based experiments conducted in the Microgravity Materials Science Laboratory at NASA Lewis. One of the results of the analytical work showed that small-scale Kelvin-Helmholtz and Rayleigh-Taylor instabilities can be generated by g-jitter at the interface of the two fluids. These instabilities can cause chaotic mixing of the fluids, greatly affect the nucleation rate of crystals, and cause growth defects.



Flow pattern map of convection due to g-jitter

Bibliography

Duval, W.M.B.; and Jacqmin, D.: Dynamics of Two Fluids Under Periodic Acceleration. AIAA Paper 88-3728, July 1988.

Jacqmin, D.; and Duval, W.M.B.: Small Scale Instabilities Caused by Oscillations Normal to a Viscous Fluid-Fluid Interface. Accepted for publication in Journal of Fluid Mechanics.

Lewis contact: Dr. Walter M.B. Duval, (216) 433-5023
Headquarters program office: OSSA

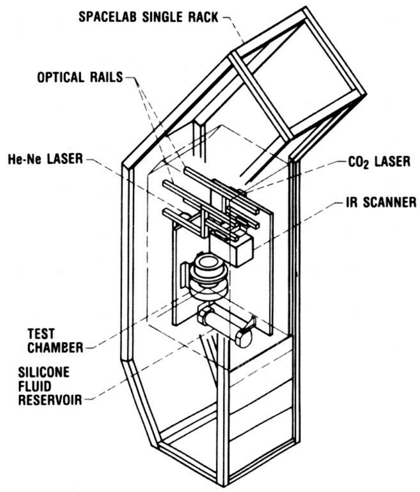
Fluid Physics

Surface-Tension-Driven Convection Experiment

Materials processing that involves solidification and crystal growth is generally expected to be dramatically improved in the microgravity environment of space because natural convection and buoyancy effects are eliminated. However, convection currents due to surface tension forces are still present. These thermocapillary flows result from the fluid motions generated by the surface-tractive force that is caused by surface tension variations due to the temperature gradient along the free surface.

Changes in the nature and extent of these thermocapillary flows can cause deleterious fluid oscillations. Numerical modeling is not adequate to predict the parameters for which these oscillations occur because of an inherent coupling among the imposed thermal signature, the surface flow, and the surface deformation. In order to complete an understanding of the physical process and develop an accurate numerical model, experimental data must be obtained in an extended low-gravity environment. Therefore the surface-tension-driven convection experiment (STDCE) was proposed for the space shuttle.

The STDCE consists of a container, 4 in. in diameter by 2 in. deep, filled with silicone oil to provide both a flat and a curved free surface that can be centrally heated either externally or internally. The cross section is illuminated by a 1-mm-thick sheet of light, which scatters from 1-μm-sized aluminum oxide particles mixed into the oil, allowing observation of the axisymmetric flow velocity.



Surface-tension-driven convection experiment for Spacelab

The preliminary design for the development of the STDCE flight hardware is an in-house project. Having successfully employed the major components in laboratory tests at NASA Lewis, we have begun to purchase flight-qualified components of an infrared thermal imager for mapping the surface temperature gradients, a carbon dioxide laser for surface heating, a helium-neon laser for illumination, and an intensified video camera for measuring fluid motion. These components will be integrated with the mechanical, optical, electrical, electronic, and structural systems that will be designed, fabricated, and tested at Lewis.

The current goal is to have experiment hardware ready for shipment by March 1, 1991, for integration into a single rack of the Spacelab module for the USML-1 mission on March 26, 1992. Technical information exchange meetings have been held during 1988 with personnel from the Astronaut Office at the NASA Johnson Space Center, the USML-1 payload mission manager and team at the NASA Marshall Space Flight Center, and payload integration personnel at the NASA Kennedy Space Center.

Bibliography

Kamotani, Y.; and Ostrach, S.: Design of a Thermocapillary Flow Experiment in Reduced Gravity. J. Thermophys. Heat Trans., vol. 1, no. 1, Jan. 1987, pp. 83–89.

Ostrach, S.: Surface-Tension Gradient Induced Flows at Reduced Gravity. NASA CR-159799, June 1980.

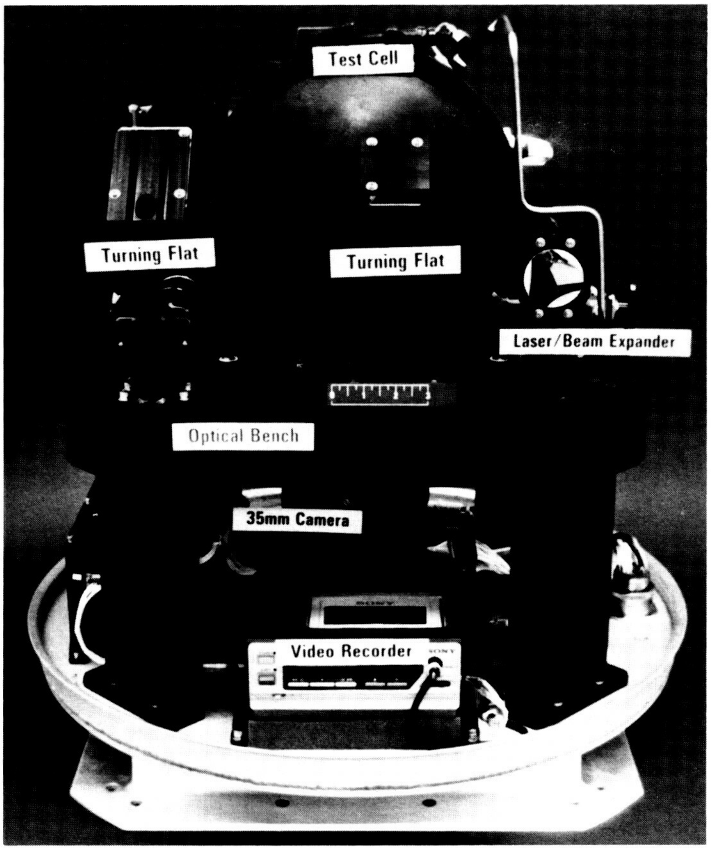
Lewis contact: Thomas P. Jacobson, (216) 433–2872

Headquarters program office: OSSA

Combustion

Zero-Gravity Droplet Combustion

Understanding the basic physical mechanisms in the combustion of single, nearly motionless hydrocarbon fuel droplets, without the masking influences of buoyancy, will allow better analytical models to be constructed. Therefore tests are being conducted to study droplet burning rates and droplet extinction diameters, a phenomenon caused by the shorter fuel vapor residence time at small droplet diameters. The analytical models provide some of the building blocks upon which computer models of fuel spray systems are developed. The results will be used to obtain better performance and higher efficiencies in future gas turbines and other commercial systems.



Droplet combustion apparatus used in Zero-Gravity Facility

In order to accurately measure droplet burning rates as well as observe interesting flame phenomena such as soot behavior, large droplets as big as 2.5 mm in diameter are studied in test chambers with oxidizing environments as high as 50 percent mole fraction of oxygen and total pressures as high as 2 atmospheres. Testing has been conducted in the two Lewis drop towers, the 2.2 sec and 5 sec (Zero-Gravity Facility). Key to experiment success has been the development of a method to grow, deploy, and ignite droplets without imparting substantial motion to the droplet. TRW of Redondo Beach, California, who has been responsible for developing the hardware on this program, has identified an opposed needle system with symmetric sparking electrodes around the droplet to provide ignition. This system has been extensively tested and refined in-house. The science data reduction and analytical model development have been accomplished by Professors Forman Williams of the University of California at San Diego and Fredrick Dryer of Princeton University.

During the course of testing, decane burning rates about 50 percent lower than those found in normal gravity were obtained. Additionally, discovery of a soot shell around the droplet and inside the flame front yielded information on a method of droplet disruption or explosion. This soot shell, through instabilities as yet unidentified, allows soot particles to enter the liquid droplet and cause the disruption by allowing accelerated heating in the local vicinity of the soot.

The ongoing research effort is currently planned to culminate in a Spacelab experiment in 1992.

Bibliography

Dryer, F., et al.: Sooting and Disruption in Spherically Symmetrical Combustion of Decane Droplets in Air. IAF Paper IAF–87–403, Oct. 1987.

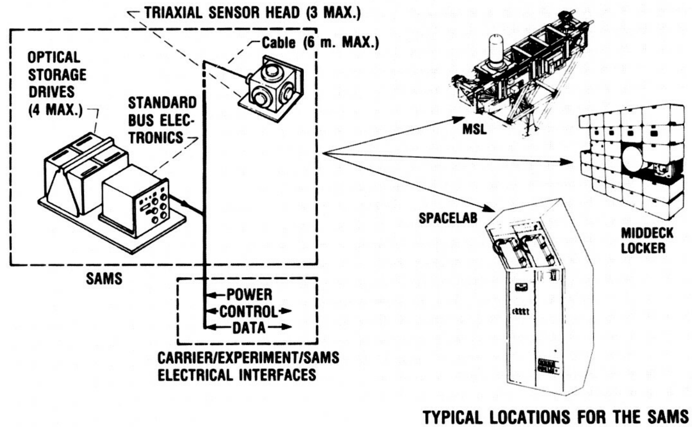
Lewis contact: John B. Haggard, Jr., (216) 433–2832
Headquarters program office: OSSA

Instrumentation

Space Acceleration Measurement System

A variety of shuttle orbiter experiments are currently under design or development as part of OSSA's Microgravity Science and Applications Program and OAST's In-Space Experiments Program. These experiments generally require measuring and recording low-gravity accelerations during space operations. Such measurements made to date have proven to be inadequate (e.g., in terms of data rate, sensitivity, and accuracy). As a result, OSSA in 1986 assigned NASA Lewis the responsibility of developing a space acceleration measurement system (SAMS) capable of serving a wide variety of space experiments.

The design of this system takes into consideration requirements for microgravity experiments located in the shuttle orbiter middeck and bay and in Spacelab. In addition to measuring, conditioning, and recording accelerations the system will be capable of performing complex calculations and interactive control. The main components consist of a remote triaxial sensor head (up to three per unit), a microprocessor-driven data acquisition system, and an optical storage device (up to four per unit). In operation the triaxial sensor head produces output signals in response to acceleration inputs. These signals are amplified, filtered, and converted into digital data that are then transferred to optical memory. The system design is modular so that both the software and the hardware can be upgraded as technology advances. The microprocessor used is code compatible with the IBM PC-XT. The electronics package employs complementary metal oxide semiconductor (CMOS) technology and a modular interconnection system.



Space acceleration measurement system

The resultant SAMS unit is a compact, lightweight, low-power instrument capable of measuring microgravity accelerations at three different experiment sites simultaneously. With its state-of-the-art components the SAMS unit can sample at rates up to 500 samples per second and record in excess of 200 megabytes per optical recorder drive without operator intervention.

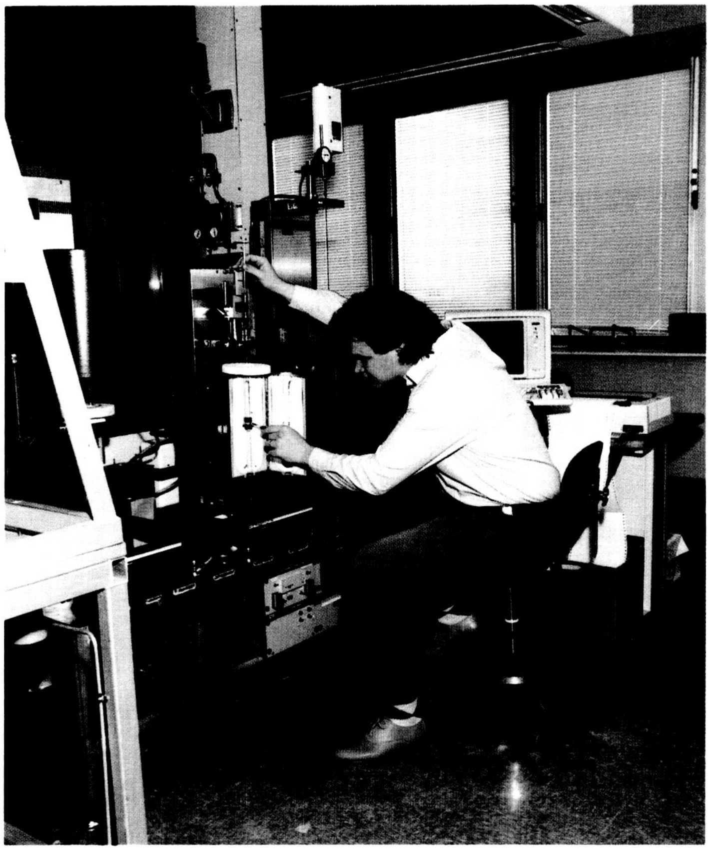
The SAMS Project is managed and implemented in-house by a team of Lewis and support service contractor (Sverdrup Technology, Inc.) personnel. Six complete acceleration measurement flight systems will be built and tested under this project. This includes the design and implementation of all corresponding software, safety and integration documentation, and ground support hardware. As part of the software development effort the SAMS Project team will implement user-driven requirements for specific experiments and will develop and supply, as required, the SAMS data-reduction software package.

The design of the electronic system was completed in 1986 and most of the hardware was acquired. Fabrication of parts, software implementation, and system component testing proceeded through 1987. A prototype model of the SAMS unit was demonstrated at the critical design review for the Get-Away Special (GAS) can application held in October 1987. In 1988 the project was redirected from the GAS can to the Spacelab accommodations. The engineering unit for two Spacelab applications (viz, the center aisle and Shuttle Middeck Experiment (SMIDEX)) is to be completed by December 1988, at which time it will be tested for electromagnetic and radio-frequency interference. While environmental testing is being completed on the engineering unit, assembly of the first flight unit will proceed. According to current schedules, the first flight unit will be ready for a preshipment review by September 1989.

Lewis contact: Richard DeLombard, (216) 433–5285
Headquarters program office: OSSA

Microgravity Materials Science Laboratory's Ceramics and Glasses Section

As part of its ongoing effort to diversify its resources, the Microgravity Materials Science Laboratory (MMSL) has opened a ceramics and glasses section. Like the rest of the MMSL facilities, it is open for use by scientists from U.S. industry, academia, and Government laboratories who desire to pursue investigations in microgravity materials processing. The new ceramics and glasses section houses the MMSL's functional duplicate of the acoustic levitator used in flight experiments. This single-axis design creates standing waves between its 15-kHz source and a reflector. Samples are trapped in the low-pressure nodes of the waves, holding them free of container walls and thus eliminating one source of heterogeneous nucleation sites. The acoustic levitator is available to researchers who desire to become acquainted with its operating characteristics.

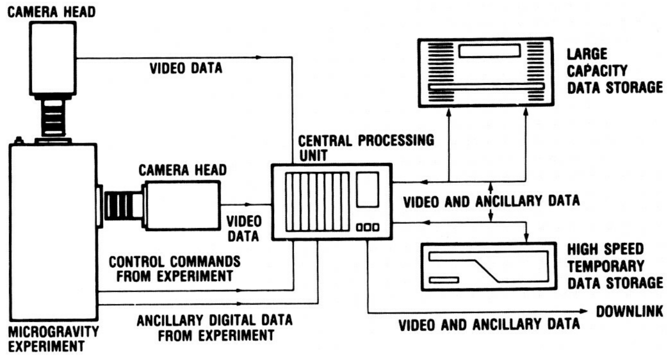


Examining glass sample in viscometric system of new MMSL section

The MMSL's ceramics and glasses section also offers a range of characterization tools that can aid researchers in pre- and postflight analysis as well as in thorough ground-based investigations. Critical cooling rates can be determined by using a 700-W spot heater focused onto a 1-cm^3 volume. A hot-stage microscope permits optical observation of transition phenomena at temperatures as high as 1700 °C. Softening point measurements can be made either by using a penetrometer or by observing fiber elongation as a function of temperature. A three-stage viscometry instrument is able to measure viscosities over a wide range. Equipment to measure internal stresses and electrical properties is also available, as is an automated thermogravimetrics system. Several high-temperature furnaces (annealing, rapid temperature, and general purpose) give researchers ready access to sample processing.

Lewis contact: Mark J. Hyatt, (216) 433–3248
Headquarters program office: OCP

High-Resolution, High-Frame-Rate Video Technology



High-resolution, high-frame-rate video

High-resolution, high-frame-rate video technology (HHVT) is an advanced technology development program whose objective is to provide technology enhancements for microgravity science experiments requiring high-speed, detailed optical data. HHVT would lift some of the data storage, management, and transmission constraints currently imposed on experimenters by today's film recording and video technologies. HHVT could also provide an experimenter on the ground more control over an experiment in flight. Potential benefactors of HHVT are microgravity experimenters, largely in combustion science, fluid physics, and materials science.

User requirements and technology capability surveys performed over the past years indicate that the imaging requirements of some microgravity experiments exceed the capabilities of state-of-the-art video system components, especially image sensors. For this reason two parallel development efforts are being pursued. The phase 1 system development will focus on delivering a state-of-the-art system with commercially available components. This system will be integrated and tested at Lewis and will be made available for adaptation to near-term microgravity flight experiments. The phase 2 development will strive to push the state of the art in order to satisfy more user requirements. This system will feature components specially developed by industry for HHVT, including a high-speed, multiple-output imaging device. The benefit of the two-phase development is that it places a state-of-the-art system in the hands of users as soon as possible for evaluation and allows that system to be expanded and enhanced as technology progresses. Some key features of both systems include the ability to trade off frame rate versus resolution in order to satisfy a broader range of requirements, a pretriggered burst mode to capture high-speed events, and subframe scanning and tracking capability, made possible by addressable image sensors.

The central processing unit will be capable of supporting multiple camera heads as well as ancillary digital data from the experiment, which will be inserted into the video data stream. High-speed data will be captured by the temporary data storage device. These data may be either downlinked directly or routed to the large-capacity data storage device for archiving or delayed downlinking.

On May 11–12, 1988, the HHVT Workshop was held at Lewis. Participants included representatives from the microgravity science community, industry, and the HHVT development team. Conceptual designs of the phase 1 and phase 2 systems were presented and favorably received by those in attendance. Requests for proposals for a high-speed data storage device and the phase 2 imaging device will be issued early in fiscal 1989.

The HHVT Development Laboratory will tentatively be located in Bldg. 16 at Lewis. System development, testing, and evalution will be conducted at this facility.

Lewis contact: William K. Thompson
(216) 433–2638
Headquarters program office: ATD

High-Burst-Rate Link Evaluation Terminal

In support of the Advanced Communications Technology Satellite Project, NASA Lewis is developing the high-burst-rate link evaluation terminal. This versatile and adaptable experimental test facility will support various ACTS technology experiments such as the characterization of the multibeam communications package on the satellite and adaptive uplink and downlink radiofrequency power augmentation.

The terminal will operate at burst rates of 110 and 220 Mbps. Data rates are discretely variable from 1.54 to 44.74 Mbps. The digital subsystem has been designed and built in-house. Uplink power will be provided by a 30-GHz traveling-wave-tube amplifier that delivers 50 W of saturated radiofrequency power. The receiver subsystem will use a low-noise receiver built by Harris Corporation for the ACTS proof-of-concept program. Also, from that program will be a 4.7-m-diameter antenna built by Scientific Atlanta. An upconverter subsystem will be built in-house as will the loopback and calibration subsystems. The loopback subsystem permits an end-to-end check of the terminal without open-loop operation. The calibration subsystem provides reference signals to calibrate the beacon receiver.

The terminal design is essentially complete. Subsystem components have been received and are undergoing acceptance tests. The project is on schedule, within budget, and meeting technical objectives.

Lewis contact: Gerald J. Chomos, (216) 433-3485
Headquarters program office: OSSA

ORIGINAL PAGE
COLOR PHOTOGRAPH

Computational, Information, and Communications Capabilities

Strategic Objective

- To provide the state-of-the-art computational equipment and software needed to meet growing needs in all facets of our work, including scientific computing, data acquisition and analysis, information systems, and communications, and thereby transform the Center into a model of excellence in these fields.

ORIGINAL PAGE
COLOR PHOTOGRAPH

Lewis Information Management System

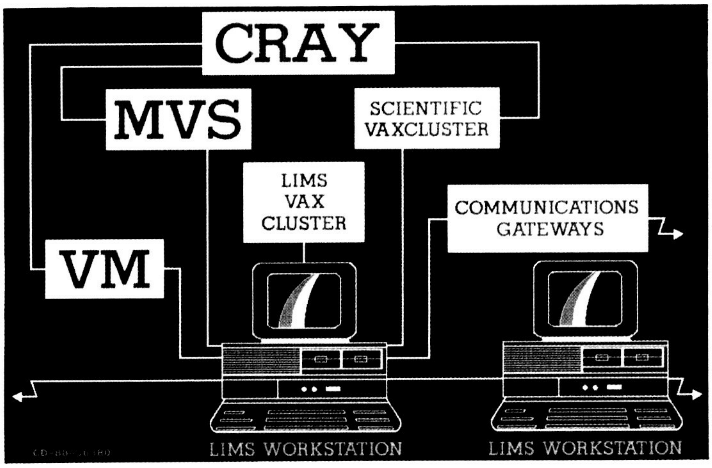
NASA Lewis is in the process of implementing an information management system that addresses several issues. Lewis had been providing centralized computing services from five different mainframe systems, each using a different operating system and requiring a different type of terminal access. In addition, a variety of different word processing systems and desktop computers had been put into use throughout the Center. The need for improved interoffice communications and general office support was beginning to emerge. The Lewis Information Management System (LIMS) was conceived to address these issues.

LIMS may be regarded as a public utility that provides several services to the desk of the end user: access to all the mainframes, personal computing services, and electronic office support. Networking is provided by a series of local area networks, one in each of the 24 major office buildings at the Center, all bridged together through an interbuilding broadband network. Primary services are provided by a centrally located server system.

At the desk of each end user is a personal computer. That computer contains the basic communications and terminal emulation products, a standard word processing package, and whatever personal applications the user wishes. The central server provides office support in the form of electronic mail and time management services, as well as a centralized version of the word processing package. In addition, electronic spreadsheet, graphics, data base, statistical analysis, and project management tools are provided.

The project, which began on May 1, 1987, provides all support services, including training, operations, maintenance, and a central help desk. In the first year three buildings have been completely cabled and more than 400 users have been trained and joined to the network. During the second year the Administration Building, all supervisors and secretaries, and selected offices will be added to the system. We anticipate that the Engineering Directorate and the Office of the Comptroller in their entirety will be on the network by the end of this year, for a total of more than 1000 users. A total of 3000 civil service and resident support service contractor personnel will be served by the system.

Lewis contact: Ernest Roberts, Jr., (216) 433-5183
Headquarters program office: OAST



Flow chart of Lewis Information Management System

High-Speed Network Supports Remote Computer Graphics

A technique has been developed that uses high-speed computer networks to provide access to a common computer graphics environment from a variety of computers. Most graphics applications at NASA Lewis currently use the Lewis-developed GRAPH3D graphics package. This package has evolved over the years into an extremely powerful and versatile tool for displaying scientific data on numerous state-of-the-art devices. However, much of GRAPH3D's performance has been achieved by tailoring it to specific computer environments—the older, but now obsolete, TSS and the newer VM operating systems running on the IBM 370 type of mainframe computer. As applications move into other computing environments, in particular the Cray X/MP supercomputer, the DEC VAX scientific computer cluster, and the UNIX-based computing systems, there is the need to maintain full GRAPH3D capability. It is not feasible, however, to redevelop and maintain GRAPH3D, which consists of over 150,000 lines of code, for each of these other systems.

The "remote GRAPH3D system" now allows the various computer systems at Lewis to communicate with the VM computer system upon which GRAPH3D runs and transmits the user-requested graphics commands, subroutine calls, and data via a high-speed Ethernet network. Although all graphics are actually performed by the VM computer, it appears to the user that they are being performed by his local computer. All connections are established automatically, and commands and data are encoded and buffered to minimize network utilization and yet maximize interactive user response.

Use of this system has preserved numerous programs that use GRAPH3D but need to run on one or more of the Center's various computers. It also gives users on any of these computers access to all the high-quality graphics devices that GRAPH3D supports.

Lewis contact: Dr. Jay G. Horowitz, (216) 433-5194
Headquarters program office: OAST

GASPLUS—A Fluid Physical Property Code for Liquids, Gases, Solids, and Mixtures of Fluids

Modeling the various systems in the NASP program requires physical properties of pure fluids, fluid mixtures, and slush hydrogen. GASPLUS was created to integrate all of these properties into a single code. Its user-friendly Fortran 77 software allows the thermodynamic and transport properties of many fluids and fluid mixtures to be calculated over wide ranges of temperature and pressure.

There are two codes within GASPLUS: a user-friendly interface to existing NASA Lewis pure fluid codes, and a new code for fluid mixtures. The pure fluids represented by the first code are cryogens such as the various hydrogens (ortho, normal, and para), oxygen (O_2), nitrogen (N_2), methane (CH_4), carbon monoxide (CO), carbon dioxide (CO_2), water, argon (Ar), neon (Ne), and helium (He). This software

generally reproduces National Bureau of Standards (NBS) data to within 1 percent.

The new, mixture, code within GASPLUS generates thermodynamic properties independent of the existing Lewis codes. It combines pure fluid transport properties from the Lewis codes with accepted "mixing rules" to estimate transport properties for mixtures. Supported mixtures include air (either "standard" composition or with varying amounts of O_2, N_2, Ar, CO_2, Ne, and He), wet air, hydrogen mixtures, and aqueous ethylene glycol. The code will predict properties for these fluid components as pure fluids or as fluid mixtures (liquid, vapor, or solid phases). It will also predict properties for saturated vapor/liquid or solid/liquid (i.e., slush) phases of pure fluids or mixtures. Because of these capabilities "flash" routines are available that accept known pressure and overall enthalpy or entropy and composition and predict the resulting temperature, types of phase, phase quantities, and compositions.

The methods used in the mixture routines are "engineering" grade in that they predict properties to within 3 percent of available NBS mixture data. However, they are much more flexible since one of GASPLUS' features is the ability to predict properties of varying composition mixtures. GASPLUS is oriented toward cryogen and mixture properties. Although it can evaluate properties at elevated temperatures and pressures, it is not intended for combustion calculations per se since it does not predict properties for dissociated species nor does it contain high-temperature reaction kinetics or equilibria.

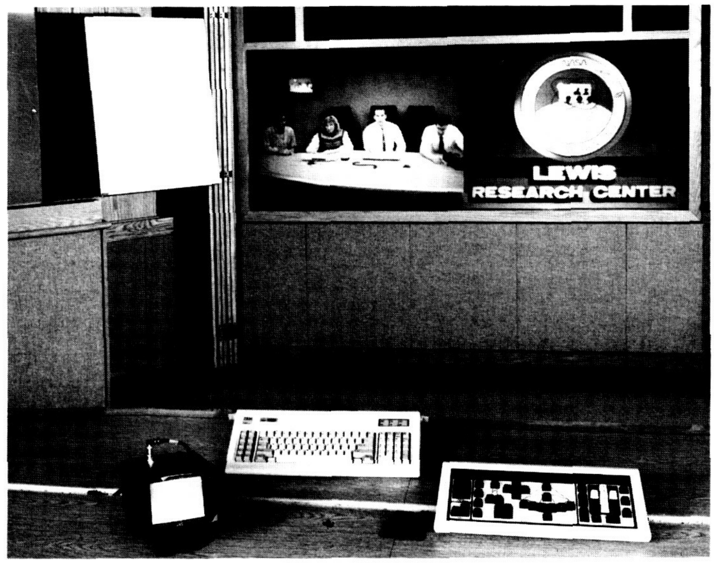
GASPLUS was written on a VAX system and is known to run on IBM mainframes (VS compiler). Because of some non-ANSI Fortran in the pure fluid routines, GASPLUS cannot be compiled on CYBERS. It can be compiled by using the Lahey compiler on PC's, but it requires at least 1 megabyte of real memory for execution. Both interaction (i.e., a "table lookup") and subroutine-callable versions are available from the Lewis contact, as is the users manual.

Lewis contact: J. Robert Fowler, (216) 433-2474
Headquarters program office: OAST

Lewis Video Conferencing Facility

The Lewis Video Conferencing Facility (VCF) became operational in February 1988. Equipped with concealed cameras, microphones, soundproofing, lighting, and computer equipment, the VCF can be used to transmit live broadcasts of groups assembled at Lewis to a remote group. In the 6 months that it has functioned, it has been quickly accepted as an ideal way to cut travel costs both in time and money. It has also greatly enhanced productivity in allowing the researcher more freedom in the frequency of meetings and large group involvement.

State-of-the-art graphics capabilities, videotapes, and 35-mm slides are all available to the participants to further communications between NASA centers. A commercial video conferencing network allows Lewis to communicate with aerospace contractors throughout the country.



Video conferencing facility

Lewis contact: Roger R. Schulte, (216) 433-5069

Expansion of Research Analysis Center

The existing Research Analysis Center is being expanded by approximately 50 percent to accommodate increased requirements for computing resources, support, and personnel. The original structure is a centralized computing facility with a core containing major computer operations. The innermost ring contains support services with direct access to the computer hardware. The two-floor outer ring contains offices that do not usually require direct access to the computer hardware. Mechanical functions are located along the rear of the building, which is the west wall.

The expansion continues the same concepts. The computer operations area is expanded directly to the north with an additional operations area on the second floor. Support areas enclose both new operations areas. Additional offices are on two sides of the support area as an extension of the two-story office ring. New mechanical functions are located close to the west wall, grouped near the existing mechanical spaces. The loading dock and service area are relocated on the new north wall adjacent to storage, support, and mechanical functions.

The expansion was designed to make optimum use of anticipated spaces while providing for a variety of increases in requirements. As much flexibility as possible was planned for support and user areas. Support areas contiguous to the operations area are designed for possible conversion to auxiliary computer operations or to open-architecture office space. User areas have been placed near the lobby entrance to accommodate computer users seeking assistance.

Basement facilities for storage and utility functions will alleviate the

Expanded Research Analysis Center

need for such spaces in the primary functional areas. A separate cooling tower and chiller building, along with redundant switchgear connections, will supply the mechanical and electrical requirements for the expansion and the existing building. The entire expansion structure and utilities have been engineered and constructed to allow for the vertical addition of a third and fourth floor as a visionary contingency for supporting NASA Lewis' increasing computational requirements.

Lewis contract: William H. Crell, (216) 433–5218

New Tools for Fluid and Thermal Analysis

Several new analytical tools have been implemented by the Engineering Directorate to provide better fluid and thermal analysis support for a wide range of NASA Lewis projects. The space station, the National Aerospace Plane, advanced communications technology, and several large aeronautics projects are currently using the directorate's fluid and thermal analysis capabilities for predicting system performance. Three specific significant developments are described here.

NEVADA is a radiation interchange code written by Turner Associates Consultants. It analyzes surface-to-surface radiation interchange and predicts environmental heating rates for those surfaces. The code has been purchased, installed, and tested by the Engineering Directorate and is now running under COS on the Lewis Cray X/MP computer. NEVADA will be used to support a variety of thermal analyses at Lewis, encompassing space station and advanced space radiofrequency systems technology.

SINDA'85/FLUINT is a code used primarily for analyzing thermal systems represented in electrical analog, lumped-parameter form. It differs from previous SINDA versions in its ability to integrate separate models and to solve arbitrary one-dimensional fluid flow networks with heat transfer. The code was installed and tested on the Lewis scientific VAX cluster by the Engineering Directorate and is fully operational. SINDA'85/FLUINT is currently used at Lewis to support the space station photovoltaic radiator design.

MOLFLUX is a code that predicts the flow of molecules near vehicles in the space environment. The code is used at Lewis to predict the space station contamination environment. Contamination is station- or payload-induced molecular or particulate matter (e.g., material outgassing and reaction control thruster plumes) that degrades or interferes with a measurement or sensor surface. The Engineering Directorate has installed and tested MOLFLUX on the Lewis Cray X/MP running under both COS and UNICOS operating systems.

Lewis contact: Duane E. Beach, (216) 433–2283

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